Media Independent Handovers: Network Selection for Mobile IP Nodes in Heterogeneous Wireless Networks

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As the candidate's supervisor, I have approved this dissertation for submission.

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Declaration

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This work is being submitted for the Master of Science in Electrical Engineering at the University of Cape Town. It has not been submitted to any other university for any other degree or examination.

Clifford Clifton Leonard Sibanda	29 August 2008
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Signed:

Dedication:

To the 4 women that have supported me, loved and prayed for me throughout my entire life. My mother Thandiwe, my aunt Edah, my grandmother Gogo MaNkala and my sister Caroline. Your constant love and care for me comes only second to the Love and Grace of God.

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Abstract

In Next Generation Networks (NGN), also known as 4G, Beyond 3G, Converged, Integrated and Interworked Network, user node mobility in wireless and wired environments will seamlessly cross disparate network boundaries. The effort to offer ubiquitous computing, providing access to services anywhere and anytime, strongly encourages the ability to roam across the different existing and future networks. Literature shows investigation of concepts such as Always Best Connected (ABC) when heterogeneous networks co-exist , which will work or compete with other schemes like Home Network Default (HND), Compatibility and Network Operator Agreements (CNOA) to guide network selection or access .

With the variety of available networks, the mobile node may be faced with having to decide which network to connect to. We concentrate on the network selection aspects of these envisaged mobile, overlay and integrated environment in heterogeneous networks. The standard developments by the IEEE802.21 Working group and the IETF Networking group form the base of our approach that seeks to see mobility across heterogeneous networks a reality.

We propose an IEEE802.21 Media Independent Handover Function (MIHF) based network discovery and network selection, leading to a handover. The selection may be further assisted by an MIHF capable Broker Node that is Third party to the Network Providers to provide a central yet distributed database of the available networks as encountered by the Mobile Node, to cater for Nodes with no prior knowledge of networks and software repository. A Mobile Node (MN) in our solution uses 802.21 communication messages to obtain information about foreign networks encountered before selecting the networks to connect to.

Our evaluation through simulations, shows that network selection in heterogeneous wireless networks environment for the appropriately equipped devices is greatly enhanced by the use of the Media Independent Handover Protocol. In scenarios where the mobile node has no prior knowledge of the encountered different network architectures, the use of a Broker node can, for an optimal number of available networks also greatly enhance the mobile node’s network selection by reducing the delay associated and the packet losses incurred.

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Glossary

Always Best Connected (ABC): A network selection scheme that seeks the network with the best network resources such as bandwidth, least delay etc.

Broker: An independent middleman operated service that is accountable to both the service seeker and the service provider. Provides a very helpful service, to service seekers when the number of service providers grows and the seeker has to choose**.**

Delay or Latency: Measurement of time it takes for a host or node to transmit its intended data. Usually influenced by the available resources such as bandwidth and competition for those resources by different hosts as well as the overheads involved in the setup and any other activities before the actual data transfer in this Thesis also influenced by the Network Selection time.

Handover or Handoff: The process of a host changing its point of network attachment while it has an ongoing session. Normally induced as a node is mobile and its signal received strength has gone below a certain threshold and a new attachment point is detected. In this Thesis the handover can occur even when the node is stationary and is influenced by several other factors such as cost.

Seamless Handover: Handover that ensures ongoing session continuity with little or no inconvenience to the affected terminal.

Horizontal Handover: Handover occurring between Attachments nodes of the same type and normally under the same Administrative Domain.

Vertical Handover: Handover occurring between different Administrative Domain Attachment nodes or nodes of different architectures.

Heterogeneous Networks: Networks using different architectures and possibly under different administrative domains.

Media Independent Handover (MIH): Handover that occurs between different media in the serving network and the candidate network. The networks in question may be under different administrative domains.

MIH Function (MIHF): A logical sublayer in between the link layer and the network layer in the protocol stack. The function implements the media independent information service, media independent event service and media independent command service

Media Independent Information Services (MIIS): MIHF service that provides information to a node that implements MIHF about the characteristics and services provided by the serving and neighbouring networks. The information assists in effective system access and handover decisions.

Media Independent Event Services (MIES): MIHF services that indicates changes in state and transmission behaviour of the physical, data link and logical link layers. The Event Service also indicates management actions or command status on the part of the network or some management entity.

Media Independent Command Services (MICS): MIHF services that enables higher layers to control the media access layer i.e. physical, data link, and logical link layers. The higher layers control the reconfiguration or selection of an appropriate link using handover commands.

Mobility: Motion of a node that leads to change of point attachment as the received signal strength from the current serving network point drops below a determined threshold**.**

Mobile Terminal (MT) or Mobile Host (MH) or Mobile Node (MN): A node that is changing its current point of attachment to the network due to motion.

Multi-radio operation: Implementation of several radio interfaces by a single node. This allows the node to access different architecture networks. For example a laptop may have a Bluetooth, WiFi and 3G interface and utilize them to the different network architectures that support these interfaces.

Software Defined Radio: Radio functions that are implemented through a software program. This gives the radio, the flexibility to change its behaviour if the program is changed or a different routine of the program is executed.

Cognitive or Adaptive Radio: A software defined radio that is capable of recognizing different networks spectra and through self configuration changes its transmission frequencies to suit the candidate network.

Network Discovery: The process in which a node discovers the existence or the availability of a candidate network.

Network Selection: The process in which a node selects from a variety of available/ candidate networks. This is the process which precedes the actual handover to the candidate network.

Serving Network: The network to which the node is currently attached. Before attachment the same network would have been a candidate network.

Acronyms from Tables

1. **W-CDMA** – Wideband Code Division Multiple Access
2. **TD-**CDMA – Time Division CDMA
3. **TD-S**CDMA - Time Division-Synchronous CDMA
4. **OFDM** - Orthogonal Frequency Division Multiplexing
5. **FHSS** - Frequency Hoping Spread Spectrum
6. **DSSS** - Direct Sequence Spread Spectrum
7. **GMSK** - Gaussian Minimum Shift Keying
8. **QAM**64 - Quadrature Amplitude Modulation 64
9. **BPSK** - Binary Phase Shift Keying
10. **ISM** - Industrial, Scientific and Medical radio bands
11. **RNC** - Radio Network Controller
12. **IE**_Network_TYPE – Information Element_Network_TYPE
13. IE_OPERATOR_**ID** – IE_OPERATOR_Identification
14. IE_**POA_ADDR** – IE_ Point of Attachment_Address
15. IE_POA_SYSTEM_**INFO** – IE_POA_SYSTEM_Information
16. IE_NETWORK_**AUX**_ID - IE_NETWORK_Auxillary_ID
17. IE_NETWORK_**QOS** - IE_NETWORK_Quality of Service
18. IE_**NET**_FREQUENCY_BANDS -IE_Network_Frequency_Bands
19. IE_NET_**IP_CFG**_METHODS -IE_Internet Protocol_Configuration_Methods
20. IE_NET_**MOB_MGMT**_PROT -IE_NET_Mobility_Management_Protocols
21. MIH_NET_**HO**_Candidate_Query -MIH_NET_Handover_Candidate_Query
22. MIH_**N2N**_HO_Query_Resources - MIH_Network to Network_HO_Query_Resources
23. **Mbs** -Mega Bits per second
24. **DSDV** - Destination-Sequenced Distance-Vector Routing
25. **NOAH** - No Ad-Hoc Routing Agent
26. **MHz** -Mega Hertz

Chapter 1

1.0 Introduction

The current roll out, all over the world, of the 3G wireless networks which offer a packet based traffic handling capability is expected among other things to reduce costs of network access as packet based billing is implemented. 3G networks are a stepping stone to the 4G networks, which are envisioned to encompass all the existing and upcoming technologies, being backward compatible with even the 1st generation wireless networks [1]. While the 1st generation networks are, slowly being retired, they are still a means of access in the remote parts of developing countries whose rural areas may still be totally out of touch with the rest of the world.

The packet based 3G networks also offer higher data rates and thus are expected to carry the multimedia traffic as opposed to the earlier versions of cellular networks, which were voice traffic oriented and circuit switched [2]. Thus, the integration and the interworking of the traditional data networks and these existing cellular networks is expected to offer a spread ubiquitous access to network services. The overlay and mixed positioning of these networks is expected to give a good coverage all over, as well as networks and services of choice in places of simultaneous existence [3]. We visualise the mobile node access of such overlay heterogeneous networks in figure 1.

In areas of various and several simultaneous networks existence, appropriately equipped devices may select one or more of the available networks to push traffic from one or more of its running applications [4] [41] [47]. Several approaches can be taken to make the decision as which network to attach to or which traffic to push through which network [43]. The selection process driven by the different yet complimentary capabilities and features of the different existing networks is the basis of this thesis. Thus, in the following paragraphs, we briefly introduce the features and developments leading to the co-existence of these networks broadly categorised as the cellular (telephony) and data networks.

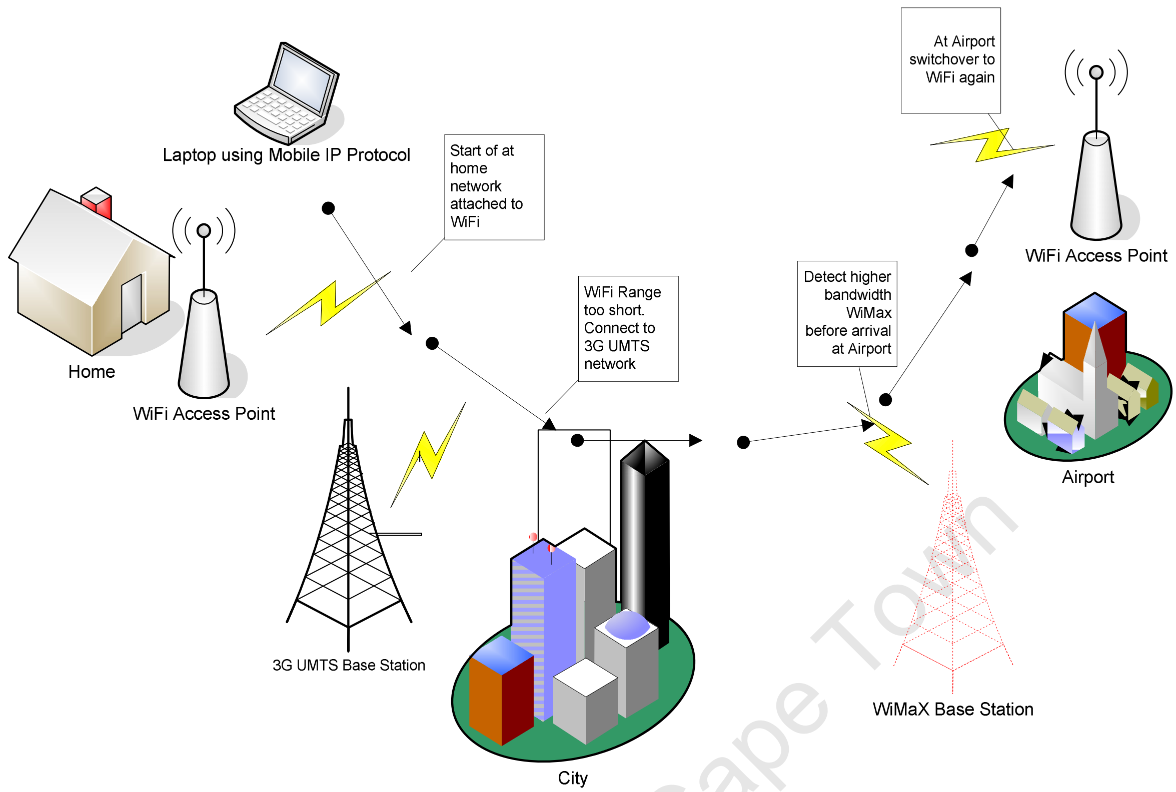

Figure 1. Mobile Internet access in Heterogeneous Environment

The different generations of the cellular networks have different capabilities and so do the traditional wireless data networks such as the IEEE802.11 networks also known as Wireless Fidelity (WiFi). As well as IEEE802.16 networks, also known as the Worldwide Interoperability for Microwave Access (WiMax) .The 1st generation networks mainly developed and introduced in the 1980s took the form of mostly wireless telephone technology, popularly known as Cellular networks, with user devices known as Cellphones. These were analogue systems that used high frequencies for transmission of voice signals to distant points without the use of wires. The main difference between 1G and 2G, the second generation of wireless networks, is that 2G networks use digital signals.

However, both systems use digital signalling to connect the radio towers, which detect signals from the handsets to the rest of the telecommunications network. The call is encoded by digital signals in 2G whereas in 1G it is only modulated to higher frequency (analogue).

Examples of the 1G system include Total Access Communications System (TACS), and Advanced Mobile Phone System (AMPS) [5]

The 2^{nd} generation networks (2G) and its upgraded versions, are present day's mostly widely deployed networks, especially in the developing countries. Examples of the 2G networks are the popular Global System for Mobile Communications (GSM). 2.5G network services enable high-speed data transfer over upgraded existing 2G networks e.g. General Packet Radio Services (GPRS) added to a GSM network. Beyond 2G, there is 3G, with higher data speeds, and 4G, with even higher data speeds, to enable new services for subscribers, such as picture messaging and video telephony [5].

1.0.1 Third Generation (3G)

3G is third-generation technology in mobile phone standards. The services associated with 3G include wide-area wireless voice telephony and broadband wireless data, all in a mobile environment. The most significant feature offered by third generation (3G) mobile technologies is the capacity to support greater numbers of voice and data customers as well as higher data rates at lower incremental cost than 2G. 3G uses 5 MHz[26] channel carrier width to deliver significantly higher data rates and increased capacity compared with 2G networks. The 5 MHz channel carrier provides optimum use of radio resources for operators who have been granted large, contiguous blocks of spectrum. On the other hand, it also helps to reduce the cost to 3G networks while being capable of providing high-speed data transmission to users. It also allows the transmission of 384kbps data for mobile systems and 2Mbps[23] for stationary systems. 3G users are expected to have global roaming between different 3G systems [2].

The second-generation networks (2G) were built mainly for telephone calls and slow data transmission. Due to the rapid changes in technology, these factors do not meet the requirements of today's wireless revolution. The developments of so-called "2.5G" (or even 2.75G) technologies such as I-mode data services, camera phones, High-Speed Circuit-Switched Data

(HSCSD) and GPRS have been ways of bridging the oncoming change to 3G networks, but are not permanent solutions.

1.0.2 2G to 3G Network Standardization

The International Telecommunication Union (ITU) defined the system guidelines for third generation mobile networks with the IMT-2000 standard. This system is called Universal Mobile Telecommunications System (UMTS). The following features cater for data transmissions in cellular networks as defined in subsequent UMTS releases [6].

Release '99

- 384 Kbit/s packet switched

Release 4

- Enhanced Data rates for GSM evolution radio (EDGE)
- Multimedia messaging
- IP Multimedia Services (IMS)

Release 5

- IP Multimedia Subsystem (IMS)
- IPv6, IP transport in UTRAN
- High-Speed Downlink Packet Access (HSDPA)

Release 6

- Wireless LAN (WLAN) integration
- Multimedia broadcast and multicast

1.0.3 Mobile data Technologies in Telecom Networks

The normal route when going from GSM towards Universal Mobile Telecommunications System (UMTS) is via General Packet Radio Service (GPRS). It offers data services to GSM users, who may be accessing the network using their cellphones. Its advantage is that the network connection is always on, so the subscriber is online all the time. From GPRS, upgrades are possible directly to UMTS, but an intermediate step of Enhanced Data rates for GSM Evolution (**EDGE**) system is available. An advantage of EDGE is that there is no new licence needed as in UMTS. The frequencies will also be re-used and no new antennas are needed. One disadvantage is that users have to buy new EDGE devices.

1.0.4 Fourth Generation (4G)

4G stands for fourth-generation cellular communication system. Only conceptual ideas of 4G are existent now, however, the features predicted for 4G have been tabled.

The 4G will be a fully IP-based integrated system of systems and network of networks achieved after the convergence of wired and wireless networks as well as computer, consumer electronics and communication technologies. It will be capable of providing 100 Mbits/s in mobile and 1 Gbits/s, indoor settings with end-to-end Quality of Service (QoS) and high security, offering any services anytime, anywhere and at affordable costs. [7] [51]. 4G is not just one defined technology or standard, but rather a collection of technologies backward compatible all the way back to the 1G networks and protocols to enable the highest throughput, lowest cost wireless network possible.

1.0.5 4G Objectives

To provide the Quality of Service and access rate requirements set by the current and future applications like wireless broadband access, Multimedia Messaging Service, video chat, mobile TV, High definition TV content, DVB, voice and data at anytime and anywhere .4G working groups have defined the following as the objectives of the 4G wireless communication standard. The standard must provide:

- A spectrally efficient system (in bits/s/Hz and bit/s/Hz/site),
- High network capacity,
- A nominal data rate of 100 Mbit/s at high mobile speeds, point-to-point connections and 1 Gbit/s stationary
- Smooth handoff across heterogeneous network, seamless connectivity and global roaming across multiple or different networks, which forms basis for our investigation
- High quality of service for next generation multimedia support (real time audio, high-speed data, HDTV video content, mobile TV, and other applications)
- Interoperability with existing wireless standards
- An all IP, packet switched network.
- 4G system should dynamically share and utilise the network resource to meet the minimal requirements of all the 4G enabled users [7] [51]

1.1 Related Work in Heterogeneous Networks Selection and Mobile Internet Access

In [8] Nirmala Shenoy introduces a Framework for seamless roaming in Heterogeneous Next Generation Networks. Focusing on overlay networks, she focuses on using Inter-System Interface Control Units (IICU), which also act as Hierarchical Inter-system Mobility Agents (HIMA). The multifunction HIMA assist the Mobile Terminals (MT) on encounters with Foreign Networks and provide information to the MT about the new encountered Network for users who have inter-network roaming mobility profile. The scheme allows a MT to register with a primary

HIMA for its incoming and outgoing connections. While her framework does not address network selection when multiple networks are encountered at the same time it does however provide with the basics of a user that discovers and connects to a new network other than the current serving network. However, of interest also to us is the multi-function HIMA that facilitates handovers in the overlay network structure.

Jukka Ylitalo, et al [9] examine mobile devices that are equipped with several network interfaces, of different access technologies, both wireless and cellular. Realizing that different requirements of different applications can result in a different preference of the interface that should be used. They suggest that Network connections should be placed in the best possible interface based on these requirements. During communication, changes in the availability or characteristics of an access network behind an interface may result in a situation where already established connections should to be moved from one interface to another. They realize that, a variety of mobility management protocols supporting handoffs between interfaces have been proposed. Some of these protocols move all traffic from one interface to another at once, while some protocols allow simultaneous communication over different interfaces. They claim that other solutions do not propose any means for the user or application to be able to dynamically influence the interface selection during the operation of a mobile device. In their paper, they claim introduction of a dynamic interface selection strategy for multi-homed terminals. Their solution is of great interest to us as the issue of dynamic network selection is part of our goals, however their architecture does not utilize the media independent handover standard and thus is is not optimized in terms of delays incurred during selection and handovers. We also hope to give a generic solution for a device whether it is multi-homed or not as long as it is equipped with the appropriate software radio or multi-interfaces.

Service Oriented Heterogeneous Wireless Network Environment (SOHWNE) that consists of services offered by service providers, radio access networks (RAN) supplied by network operators and users with various devices, is introduced by Ormond, et al [10]. Their version of the user-centric vision for the future is one where users in a SOHWNE will be free to 'shop around' not only for the service they need, but also for the available access network which meets their current service needs. Thus, users will need an optimal intelligent network selection strategy, which will aid them in picking the 'best' available RAN solution with a minimal loss of time, energy, money, and user inconvenience. The decision involves a number of complex considerations and trade-offs for conflicting selection metrics. They realise that it needs to be a highly flexible strategy applicable to both the user's professional and personal communications requirements in an ever-changing radio environment. Given the volatile nature of radio channel conditions, this decision involves a certain amount of uncertainty and risk tolerance on the user's part. Hence they introduce the 3 utilities in a later investigation, which are Utility function 1 which they present as one that takes the shape of the risk neutral users, Risk seeking user preferences are described by utility function 2 and the third utility function describes a risk adverse user. Their subsequent report is in Utility-based Intelligent Network Selection in Beyond 3G Systems [48]. Their approach that seeks to give the user the decision platform is of interest to us but we approach our solution from the Media Independent Handover standard as opposed to their suggested Risk utilities. Our interest in their work is user centric approach to service provision as our investigation seeks to empower the user to select networks, as they prefer.

Again Ormond [11], et al further examine a Network Selection Decision in Wireless Heterogeneous Networks, a user-centric approach, which they say, allows a user to choose a network which meets their requirements best. Their network selection algorithm predicts the data rate on each interface available to the mobile node and decides based on the predictions. Their approach is of great interest to us, we believe our MIH introduction, and Broker service optimises this user centric approach.

Latvakoksi E.J and Laurila, P.J [12] introduce Application based access system selection concept for all IP mobile terminals. Their provided concept hides the access technology selections from the user, and makes it possible to carry out selections automatically. The optimal access type is automatically selected based on the required QoS of the service as required by the running application, before any user traffic is transmitted over the all IP mobile Internet. These basic concepts provide for the concepts that allow multiple connections by the same Mobile Terminal to multiple different networks as per application needs. Our solution, which follows the generic and standard approach of the Media Independent Handovers, seeks to allow more than just the application requirements to govern the network selection.

Cost is main driving factor in network selection in the paper by Wei Shen and Qing-An Zeng [13]. Their paper identifies that no single type of existing wireless and mobile network can provide all types of services, e.g., wide coverage and high bandwidth. Thus, an integrated wireless and mobile network introduced by combining different types of networks can provide more comprehensive services. In an integrated wireless and mobile network, a mobile terminal equipped with heterogeneous network interfaces can connect to different types of networks. How to select a desired network is an important issue in the integrated wireless and mobile network. They realize that some network selection strategies have been proposed, most of them are designed to meet users' needs, such as bandwidth, money cost, or power consumption. Their paper, proposes a cost-function-based network selection (CFNS) strategy in an integrated wireless and mobile network from system's perspective. We look at a more comprehensive solution which can take into account cost as well as other factors according to the user requirements.

"Always Best Connected" one of the mostly widely researched and pushed idea for Heterogeneous Networks access is well examined by Eva Gustafsson and Annikka Jonsson [14]. According to them The Always Best Connected (ABC) concept allows a person connectivity to applications using the devices and access technologies that best suit his or her needs, thereby combining the features of access technologies such as DSL, Bluetooth, and WLAN with cellular systems to provide an enhanced user experience for 2.5G, 3G, and beyond. An always best connected scenario, where a person is allowed to choose the best available access networks and devices at any point in time, generates great complexity and a number of requirements, not only for the technical solutions, but also in terms of business relationships between operators and service providers, and in subscription handling. They attempt to describe the concept of being always best connected, and then discuss the user experience and business relationships in an ABC environment, and outline the different aspects of an ABC solution that will broaden the technology and business base of 3G. While we appreciate the approach of the always best connected scheme to network selection, we believe the best way to achieve this is through the use of the Media Independent Handover and Broker services which their paper does not clarify as to how the ABC is achieved.

Petteri Poyhonen et al, envisage that in future wireless communication systems using Ambient Networks technology the users will be able to use a multitude of networks. Flexible and frequent roaming between networks will be a key characteristic of mobile services and the terms "home" and "visited" networks will be common at local and national level. Realising that the Ambient networks concepts will enable operators to co-operate in new ways and allow users to connect to a multitude of "visited networks" although the user is within coverage of the "home network". Their investigation borders on how operators and users can exploit the flexibility in selection among different access options. Their working questions are: How will traffic load and network utilization change? Will the user experience mainly be of the type "free to choose"? In addition, Will the service quality be improved? What impact will different types of operator cooperation and agreements have? Their overall approach is business oriented and gives an industry perspective of this research area [15]. From their paper we appreciate the business oriented approach to the problem statement. The pros and cons for a business to co-operate in heterogeneous networks especially in view of the overall network utilization is a very important aspect of any implementation. While our solution does not have an industry or business input, we acknowledge that Poyhonen's paper cannot be simply overlooked.

Yui-Wah Lee and Scott C. Miller [16], in their paper Network Selection and Discovery of Service information in Public WLAN Hotspots propose their own solution which they call Roaming Information Code (RIC). They claim that RIC can be transported as Service Set Identification (SSID) or a new Information Element of the 802.11 standard. Lee and Miller state that RIC is scalable and can be fully backward compatible with existing APs (if transported as SSID). They say it does not hinder fast handoffs. They also expand it to two other schemes - a scheme called RIC-VAP for provider-specific security information; and a scheme that allows an AP to announce price and workload information. While their solution is in homogenous network environment we realise that they offer a solution which seeks to allow connectivity in different Network ID environment, which are identified through SSIDS. We believe our solutions as outlined in the Media Independent Handover Standard Draft can also cover this scenario and thus believe their paper is of relevance to us.

1.2 Problem Statement

In the all IP Core Next Generation Networks, it is envisaged that a user with a capable device will be able to traverse and access different networks of different architectures that may be in different administrative domains seamlessly, resulting in enhanced user experience [3] [4]. This ability to access different networks presents the mobile terminal/ user with the problem of having to choose which network to connect to once it encounters more than one network that are available for it to connect and more so as the number of the number of the networks increases. If the user is in motion and it is eminent that the mobile terminal must effect a handover in a heterogeneous environment, while the user is in an ongoing session, the need to make the network selection as short as possible is paramount to ensure as little data loss and delay as possible. This will limit and reduce data loss and delay as they are undesirable in seamless connections thus ensuring better user satisfaction.

Hence, to realise seamless handovers, networks selection is an important part. If the user is stationary and the serving network conditions have changed such that there is need to handover to a different available network, similarly the importance of a quick and seamless handover cannot be over emphasised. Overall, when encountering the problem of selecting which network to connect to, several factors may come into play. For instance, the cost of connecting that network, the resources available in that network e.g. bandwidth as well as other metrics associated with that network such as security and latency may be some of the factors considered by a mobile node when selecting amongst the available networks.

1.3 Scope of Research

This research focuses on the network selection part of handover in a heterogeneous network environment. While some of our evaluations are based on achieving targeted handover to networks selected, the actual handover after the selection of the network is beyond the scope of this thesis is. Also beyond this thesis' scope, is Call Admission Control (CAC), resource allocation for admitted calls/connections as well as authentication and security. Thus in our investigation, we assume all available networks can allow any MN to utilise its resource when queried and when selected.

Objectives and Proposal:

With this focus, we hope to make the following contributions:

- Primarily design an optimised and standard network selection process for capable devices in a heterogeneous wireless networks environment
- Design a network selection process that is informed and therefore ensure a best selection outcome based on implemented policy
- Our approach affords user defined policies to be effectively used to effect selection, thus we hope to overall enhance user satisfaction.
- Our optimised solution should reduce the time and packet loss incurred during the network selection process
- Thus, the reduction of the time and packet loss during the network selection should further reduce the delay and packet loss incurred during the whole process of media independent handovers.

1.4 Thesis Outline

The whole of this thesis is organised as follows:

In Chapter 1, we give an introductory background building up to our research, in which we give an overview of mobile internet access, review of related work and outline the problem statement with our solution proposal. The introductory background serves to show the attractive features of the heterogeneous networks that primarily influence the selection process.

Chapter 2 reviews the media dependent network access specifications in the existing networks. In this chapter, we examine the boundaries that exist between Heterogeneous networks that have always made network selection or network access to networks using different media not possible for user devices. We also attempt to show the complimentary advantages of being able to access the disparate networks as none can offer the pervasive coverage, bandwidth, cost, QoS or power requirements of user devices at all points of the user's need. In the next generation networks, the ability to select and access the network of choice is greatly encouraged.

In Chapter 3, a stationary user or mobile user primarily can undertake Network Selection if a choice exists. The stationary user, that changes attachment whilst maintaining current connections, due to the implementation of the Internet has to implement Mobile IP as in a mobile user in order to cater for handover process in terms of the network layer requirements for routing purposes. This chapter looks into the next generation networks promises of mobility and media independent handover in the existing networks and future networks. The role of the media independent handover function is examined.

In Chapter 4, we look at Network Access Selection in Heterogeneous environments. Reactive and proactive network selection in response to conditions and events is the basis of discussing the scenarios where the selecting node has access to the information that can assist the selection information and the manner that it obtains this information.

Chapter 5 has our design for our system model, both the architectural and functional designs. We examine the configurations necessary to carry out the selection process. The design examined is developed into a simulation platform for evaluation.

Chapter 6 delves into our simulation work and results obtained. We also give analysis of the results and the whole investigation and conclusions on the thesis objectives and our findings. Due to lack of time and resources, we cannot cover all the investigations that will afford the user seamless and ubiquitous network access, we therefore suggest recommendations of future work in this research area.

Chapter 2

2.0 Existing Media Dependent Selection Specifications

Telecommunication thrives on the ability to transmit a signal from point A to point B, with the least possible interference if not totally none [17] [46]. Hence much of the preoccupation of Telecommunication engineers has been to produce systems and client terminals that can operate in the same environment with insignificant or no interference. This would normally entail producing systems and client terminals that operate only in a certain range of specifications e.g. frequency. Thus, despite the availability of other systems that are outside this range, the device would indicate that it could not detect any network if its peer (same specifications) network device is unavailable.

Further more the use of network IDs such as SSIDs can lead to devices reporting e.g., "that there is no network available", yet it is detecting another network with same specification as it has but just a different network ID [18]. Clear examples of these scenarios can be taken from a GSM cellphone that subscribes to a network provider such as MTN in South Africa, if that GSM device using 900MHz is in a room that is covered by a WiFi network using 2.4GHz but unable to detect the GSM network it traditionally will not function. Similarly if the same device is only able to detect a GSM network that is using 900MHz but that belongs to another network provider Vodacom in South Africa, it will once again report unavailability of the network.

At the height of its success, Internet access is highly guarded against unauthorised use and any malicious access [42]. Firewalls and intrusion detection systems are implemented in virtually all networks and thus making the question of connection to heterogeneous networks in different administrative domains a difficult area to ensure in the seamless handovers task. Thus, we recognise the huge task of mobile nodes accessing heterogeneous networks that are not in their administrative domain. However, security issues are assumed to be resolved, in our thesis and left as possible future work, and concentrate on the network selection process without these hurdles.

2.1 Media Dependent Access Overview

Network selection in heterogeneous networks is only possible if the accessing device is adequately equipped to access the candidate network. As such, it important to note the device may have to possess multiple interfaces or software defined interfaces. In existing networks, if a single network interface card is in use, there are specifications that indicate what the capabilities of the device using the interface are.

These specifications would normally indicate the frequency range, which the device is capable of detecting and transmitting. On an 802.3 network because it uses a wired and guided media, which may be of voice grade, this range may be in Human speech range of 800Hz to 3.4KHz, whilst a GSM interface maybe in the 900/1800MHz in most countries and either 2.4Ghz or 5GHz if using a 802.11 interface. The specifications also indicate the bandwidth possible and in most cases allows for degrades if the network conditions change, e.g. an 802.11a interface is capable of up to 11Mbs, whereas an 802.11g is capable of up to 54Mbs down-gradable to 11Mbs.

Specifications can also indicate the power ranges that the device is capable of operating in. All these specification must match the peer node that the device is connecting to. In this Thesis, we examine the specifications for an IEEE802.11, IEEE802.16 and UMTS networks interfaces.

2.2 Physical Layer Access Requirements

Physical Layer (PHY) specifications for the 3 types of wireless networks in question are inherently different. We consider the spectrum, modulation, bandwidth usage, distance range, mobility support, interface and cost of spectrum aspects of UMTS, WiMax and WiFi Networks. The advantage of interworking and overlay arrangement of these networks is realised in the complimentary features that the networks offer. For example, WiFi networks generally offer lower access costs, WiMax offers bandwidth and coverage distance and UMTS offers the distance and optimised mobility. They are examined comparatively, and represented in the table 1 [19] [20] [21].

Table 1. Physical layer Characteristics in WiFi, WiMax and UMTS [19-23]

	UMTS	**WiFi**	**WiMax**
Spectrum	1885-2025MHz Uplink 2110-2200MHz Downlink	2.4 GHz 5GHz	{802.16e} 2-6GHz {802.16a,d} 2-11GHz {802.16} 10-66GHz
Modulation	W-CDMA[1], TD-CDMA[2], TD-SCDMA[3], OFDM[4]	FHSS[5], DSSS[6] {802.11b}, OFDM {802.11g} GMSK[7]	QAM64[8], QAM16, OFDM {802.16e}, BPSK[9]
Bandwidth	Theoretically 14Mbs Practical for now is 2Mbs. 3GPP plans 100Mbs Downlink and 50Mbs Uplink	{802.11b} 11Mbs {802.11a} 54Mbs (802.11n >100Mbs)	Theoretically up to 134Mbs 70Mbs {802.16e}
Distance Range	3-8km	100m	5km {802.16a,d}30-50km {802.16e}
Mobility Support	Yes	802.11g	802.16e
Cost of Spectrum	Very Costly	Free ISM[10] band 2.4GHz	Average Cost {recommended for Rural Installations}
Interface	Generic Radio Access Network (GeRAN)	Access Points	RNC[11]

2.3 MAC Layer Access Requirements

The same networks examined at the Media Access Control (MAC) layer show that, the UMTS network as it strongly derives from cellular networks which normally are PHY/MAC networks, has most if functional characteristics in this layer. Mobility is also inherently implemented in this layer for UMTS as compared the WiFi and WiMax's network layer mobility solutions. The Radio Link Control (RLC) and Media Access Control (MAC) together control user access to the transmission medium. As well as multiplexing data from multiple sources (logical channels) onto transport channels as well as, segmentation and reassembly, ciphering, and reliability of radio transmission. WiMax and WiFi Mac Frames shown in Figure 2.

The WiFi/WLAN layer 2/MAC implements Carrier sense multiple access/collision avoidance (CSMA/CA) Mechanism. This derives from the popular IEEE802.3 (Ethernet) CSMA/CD (Collision Detection). Thus, similarly to the UMTS being more closer to the traditional cellular networks, the WiFi functional implementation is closer to the traditional data networks. Control packets Request To Send (RTS), Clear To Send (CTS) and Acknowledge (ACK) are used in the MAC layer to control media access. It also employs Automatic Retransmission Request (ARQ) to ensure reliability in data transmissions, but this is not implemented in voice cellular networks as they carry real time traffic as opposed to the traditional data networks. Channel access is controlled by use of Shortest of the InterFrame Spaces (SIFS), Point coordination function-InterFrame Spaces (PIFS) or Distributed InterFrame Spaces (DIFS). At the MAC layer, network connection is implemented through a station listening to each channel before transmission of Beacon frames having Service Set IDentifier (SSID).

a)

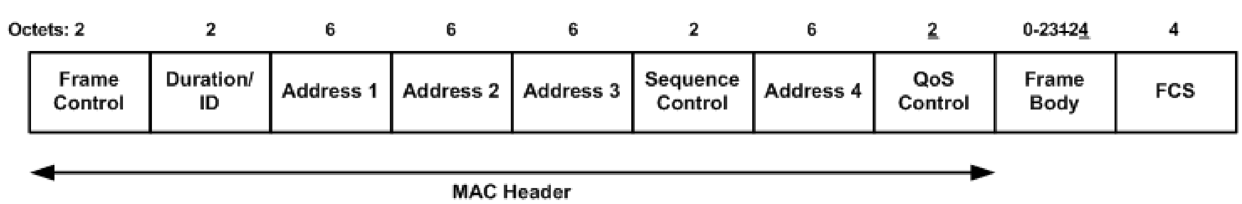

Figure 2. MAC Frame Format (a) 802.11 and (b) 802.16

b)

Type	Length	Connection ID	Header CRC	Data	CRC
Octets: 1	2	2	1	Varies	0.5

WiMax's layer 2/MAC implementation is divided into Service Specific Convergence Sublayer, MAC Sublayer common part and Security Sublayer. The Transmission convergence Sublayer in the Physical Layer interfaces via Service Access point (SAP) with the Link Layer. The MAC Sublayer implements the following Service Classes.

- Constant bit rate service
- Real-time variable bit rate service
- Non-real-time variable bit rate service
- Best efforts service [17]

Table 2. Comparison of the Media Access Control and Radio Control Functions in WiMax, WiFi and UMTS [19-23]

UMTS	WiFi	WiMax
Transport channel		
Multiplex/De-multiplex	Multiplex /De-multiplex	Multiplex /De-multiplex
Contention	Contention	Contention
Flow control		
Automatic Retransmit request (ARQ)	ARQ	ARQ
Error detect	Error detect	Error detect
Mobility		
Radio resources management		
Connection/Handover	Connection/Handover	Connection/Handover
Scheduling		Scheduling
Framing/ Segmentation and Re-assembly (SAR)	SAR	Framing/SAR
Power control	Power control	
Broadcast, paging	Authenticate	Authenticate

2.4 Network Layer Access Requirements

WiFi being a data network in nature implements network layer protocols in virtually all its network connections. Although initially developed without inherent mobility by virtue of it being wireless, it has been modified to cater for mobility in the IEEE802.11g version. However, the greatest drawback is the distance range that it can cover thereby rendering the type of mobility to a walking speed mobility within the average 100m coverage as compared to the UMTS' 3-8km coverage at driving speeds of 120km/hr. The WiMax IEE802.16e version that also allows for mobile access is also another low speed/ walking speed mobility access network even through it can cover up to 50km.

However all the 3 networks are capable of implementing the basic Network Layer, Internet Protocol (IP) and the Mobile Internet Protocol (MIP) to cater for packet routing in internetwork environment. The basic MIP operation is discussed in the following paragraphs.

The basic MIP (Figure 3), which is the underlying concept in all the mobile IP developments with several improvements of course in the subsequent versions, has an architecture shown in figure

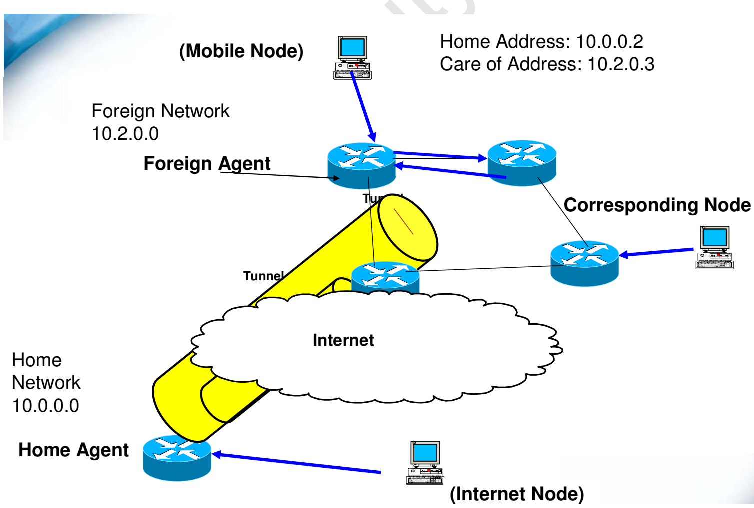

Figure 3. Mobile IP Network Architecture

Mobile Node (MN): Is user terminal of interest that can change its point of attachment to the Internet using Mobile IP. The mobile IP principle is that it maintains its original or home IP address as it moves into other subnets or networks and in conjunction with a temporary Care of Address, allocated at the Visited subnet, it can communicate with any other systems in the Internet.

Correspondent Node (CN): The end system/terminal with which the MN communicates is called CN. It can be a fixed or a mobile node. It can be a server or another user terminal.

Home network: Is the subnet to which the MN belongs.

Foreign network: The current subnet that the visiting MN is attached to but is not the home network.

Foreign Agent (FA): A network node that provides several services to the MN during its visit. The FA can have the COA acting as the tunnel endpoint and forwards packets to the MN. It is not necessary to have a FA in the MIPV6, a subsequent development that seeks to optimise the protocol. When implemented the FA is typically implemented on the router of the visited subnet.

Care-of-address (COA): Is the allocated IP address to the visiting MN by its current serving network. Binding of this address to the HA is necessary for tunnelling of all packets sent to the MN via its HA.

Home agent (HA): The HA provides several services to the MN and is located in the home network. The tunnel for the packets starts at the HA. It maintains a location registry i.e. the current COA of the MN. It can be implemented on the router that is responsible for the home network. [24].

In this thesis, all user/terminal nodes, whether stationary or mobile, implement the Mobile IP protocol, to effect handovers from one subnet or network to another available in the same location. Thus, Mobile IP nodes that attach to a different network other than the default attachment network are considered to be away from Home network.

In order to achieve ubiquitous network access, in an overlay and integrated heterogeneous environment, a mobile node needs to be adequately equipped to satisfy the specification requirements of the candidate network. Existing systems' limitations lie in the specifications of the devices, which are normally custom made to work with one system with little interference on co-existing systems. Current solutions to this involve using multiple interfaces, which are activated one at a time according to present need. Thus, each interface satisfies the protocol stack specifications requirements for its operation and interaction with its peer network interface.

However, possession of multiple interfaces by devices does not ensure continuation of user sessions if network interfaces are switched. Switching may be due to events that may be beyond the users' control or simple user preferences such as network going down and better performance network detected respectively. Switching of network point of attachment commonly referred to as handover or handoff is discussed in our next chapter of the thesis. In heterogeneous networks, we argue that this switching is effectively handled by the Media independent handover function, which we also discuss in the next chapter.

Chapter 3

3.0 Mobility and Handovers

Stationary and mobile nodes may go through the process of network selection when accessing Heterogeneous networks, for different reasons. Stationary nodes may be forced by change in conditions of the current serving network or attracted by a newly discovered link. Mobile nodes are most likely to be affected by the received signal strength as they move away from Point of Attachment (PoA). Regardless of the driving factor, the network selection process must lead to a decision and an effort to connect to the network of choice. If the node is currently attached to a PoA, a handover must take place for attachment to the new PoA to occur. The Internet and data networks will handle the handover of stationary and mobile nodes in the same way and favourably at the Network layer as discussed in chapter 2.

Traditionally, data network access is normally by stationary nodes of the network. The networks themselves have also come a long way from having static configurations to possible dynamic configurations as per need. Telecommunications as a whole has come a long way, from the days of fixed telephony only to the current days of Mobile Cellular phone communications. With the current developments of Technology seeing the convergence of the old perceived Telecommunications and Data/Internet communication, as well as convergence of the wired and wireless access Networks to services, the goal is pervasive service access [45]. The converged networks coined as 4G networks/ Next generation Networks, are expected to be all IP based serving both voice and data connections, also known as Multimedia.

Stationary nodes do not suit the mobile users who are always away from their desks and need to have access to the Home Network. Developments have gone past Nomadic mobility where a user moves to a different location and is able to the seek a re-connection to the Home Network once settled a network point of attachment, to active connections as the user moves at high speed. Authentication and Security then play an important role in these connections as the need to ensure only authorized users have access to the network and the traffic is not intercepted by malicious intruders/users.

Mobility of users at current stages on average defines users that are in motion at reasonable speeds of up to 120km/hr being able to connect to the network and maintaining their connections as they go through different areas. This is possible through process known as Handoff/ Handover. Cellular phone network access has been able to offer this kind of wireless access for a while now [49]. The limitation with data/Internet access handover that derives from the voice (cellular phone) handover is that, the algorithms are developed cater for this handover in homogenous networks. As we move into the 3G and 4G networks (Next Generation Networks) and integrate the concepts of Universal access, anywhere, anytime and any network, the need arises to come up with new algorithms that will facilitate handover in heterogeneous networks.

Traditionally this mobility is handled at different layers for some of the existing networks, with the data oriented networks handling mobility on the network layer whilst the cellular networks handle mobility in the Media Access Control (MAC) layer.

Internet access, a phenomenal development of our generation and time, has long gone past the state of being a luxury to that of a daily necessity to individuals, organisations and governments. Largely developed in the 1980s, the Internet, by the late 1990s proved that it was indispensable from any form of community whether home, commercial or government/national. Its initial growth trends lead to the cable growth trend, which saw the developments of coaxial cables, Ethernet cat 3-5 and even the Fiber optic cables in a bid to achieve even higher bandwidths for network access.

However, the insatiable appetite for network and services access by users has lead to demand for ubiquitous and seamless access for a user traversing the available networks they travel across the lands. Wireless communication in comparison to fixed or cable access is the most flexible and convenient technology that allows access to network services from virtually anywhere, as long as there is network coverage. This powerful service access technology is a potential boost for the Internet Technology, which on its own has radically changed the media and communications world in the past 2 decades. With developers, working rapidly to bring the multimedia services to mobile users anywhere, anytime and any network. Mobile Wireless Internet is therefore a welcome development just as was the birth of mobile cellular phones for the anytime and anywhere network users.

Individuals away from their home networks with appropriate devices such as Personal Digital Assistants (PDAs), Hi-Tech Cellphones and laptops can access wireless networks, communicate with their home offices, and e-mail even at airports while waiting for flights. We show a visual picture of this mobile access in Figure 1. This technology analogous to the cell phone world is very convenient for today’s lifestyles. Vital emergency calls and location tracking should be possible for rescuers to deliver relief as soon as possible. Emergency calls with, both audio and video for visuals might go a long way in saving lives. Access to online location maps, news and weather for mobile travellers. Browsing for a shopping mall location as one drives towards the sought for mall, or comparing online prices with the ones in the actual store while shopping. Booking reservations as one travels to the point of departure, are some examples that mobile data access can bring to ease our lives.

Sending information over seas is mainly through wireless network systems using satellites. Vital services such as the police communications utilize wireless networks to convey messages. Office devices use wireless networks to send and share data quickly especially in a small office building without the mess of entangling cables. Another advantage of wireless networks is that they are inexpensive and quickly connected. Wireless internet connections are currently being developed to offer mobility, which promises to be one of the best features in the Wireless Networks services.

A wireless network comes with its own disadvantages, that there can be interference that distorts the radio signals [46]. Wireless Networks are more vulnerable because anyone can try to break into a network broadcasting a signal. Many of the networks offer WEP - Wired Equivalent Privacy - security systems which have been found to be vulnerable to intrusion. Though WEP does block some intruders, the security problems have caused some businesses to stick with wired networks until security can be improved. Another type of security for wireless networks is WPA - WiFi Protected Access. WPA provides more security to wireless networks than a WEP security set up. The use of firewalls also helps with stopping security breaches and security problems in some wireless networks that are more vulnerable.

3.1.1 Overview of Mobility & Handovers

As the research into mobility grows, it has seen several dimensions of Handover/Handoff being investigated. Hence, several definitions and classifications of mobility to date exist. These include Personal mobility, which refers to individuals being able to change location and yet still have access to their normal network services. Session mobility refers to the ability for the user to change network point of attachment and yet still maintain an ongoing session. Terminal mobility, which means the user's ability to change terminal and still access services, this mobility may also be closely related to session mobility, which refers to a scenario where a user changes terminals whilst in a live session. Service mobility is ability to access a service from any point, network or terminal [25] [52].

The main types of handovers that are existent to support the mobility can be broadly classified into 2 categories of handovers, horizontal and vertical. Horizontal handover refers to a mobile node's change of network point of attachment within the same network, subnet or administrative domain, also be referred to as micro mobility. Vertical Handover refers to a mobile node's change of network point of attachment to another network or administrative domain, which can also be termed macro mobility [26].

The other possible classification of handovers, is the make before break, also known as soft handoff. In this scenario the current connection is maintained as a new connection is made to new point of attachment, which is comparable to break before make also known as hard handoff. In hard handoff, the current connection is broken before the new connection to new point of attachment is made. While mobility is more likely to cause handoff to be effected when a mobile user changes point of network attachment to a candidate point of attachment at the edges of cells due to received signal strength falling in the serving node as compared to the candidate node. This thesis extends handover to scenarios where the node in question is stationary and the received signal strength may still be very good but change is effected possible because a cheaper network node has been detected.

Generally, mobility in traditional data and internet networks such as WiFi has been accepted as best addressed in the network layer. Thus Mobile Internet Protocol (MIP) is the standard candidate to address this mobility. Research has extensively developed this concept through the basic MIP, MIPV6 to cater for the IPV6 addressing scheme, Fast Handovers MIPV6 (FMIPV6), Hierarchical MIPV6 (HMIPV6) [27].

3.1.2 Horizontal Handovers

Horizontal Handover refers to a handoff event that occurs in a single administrative domain network or handoff event that occurs across access equipment of the same architecture as shown in figure 4. This is the most common type of handover as users access the network from their service/network providers. Usually this handover is triggered by the received signal strength from the current serving network attachment going below a certain threshold

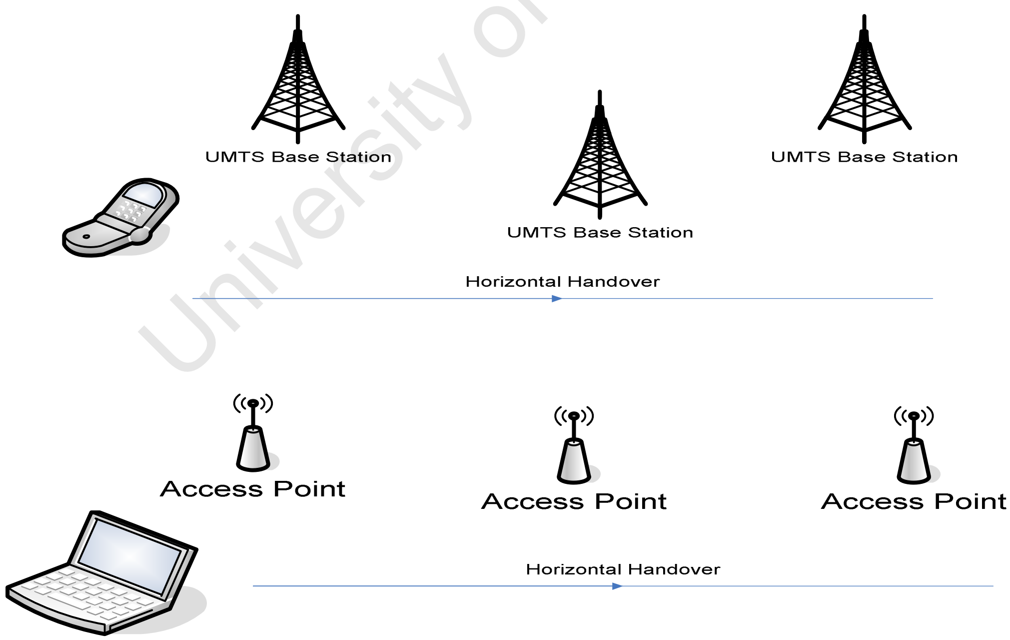

Figure 4. Horizontal Handover

3.1.3 Vertical Handovers

Vertical handover refers to a handoff event that occurs between administrative domain networks or handoff event that occurs across different access equipment architectures. We visualise this in figure 5. While this handover may occur between network architectures, that are similar, in the case of different administrative networks, there has been a considerable increase in the demand that even if the architectures are totally different it be seamlessly and effectively be handled. The use of multiple antennas and software-defined radios enable this cross-architecture seamless handover. The Media Independent Handover [28] [51] initiative seeks to ensure that there is standardisation to cater for the cross-architectures handovers whether under one administrative domain or not. The initiative by the Institute of Electrical and Electronic Engineers (IEEE) under the IEEE802.21 working group seeks to standardize handover in IEEE standard networks and non-IEEE networks such as UMTS. The working group covers wired and wireless networks in their research and regularly release a non-binding draft of the work done so far. We examine the fundamentals of the Media Independent Handovers in our next paragraphs.

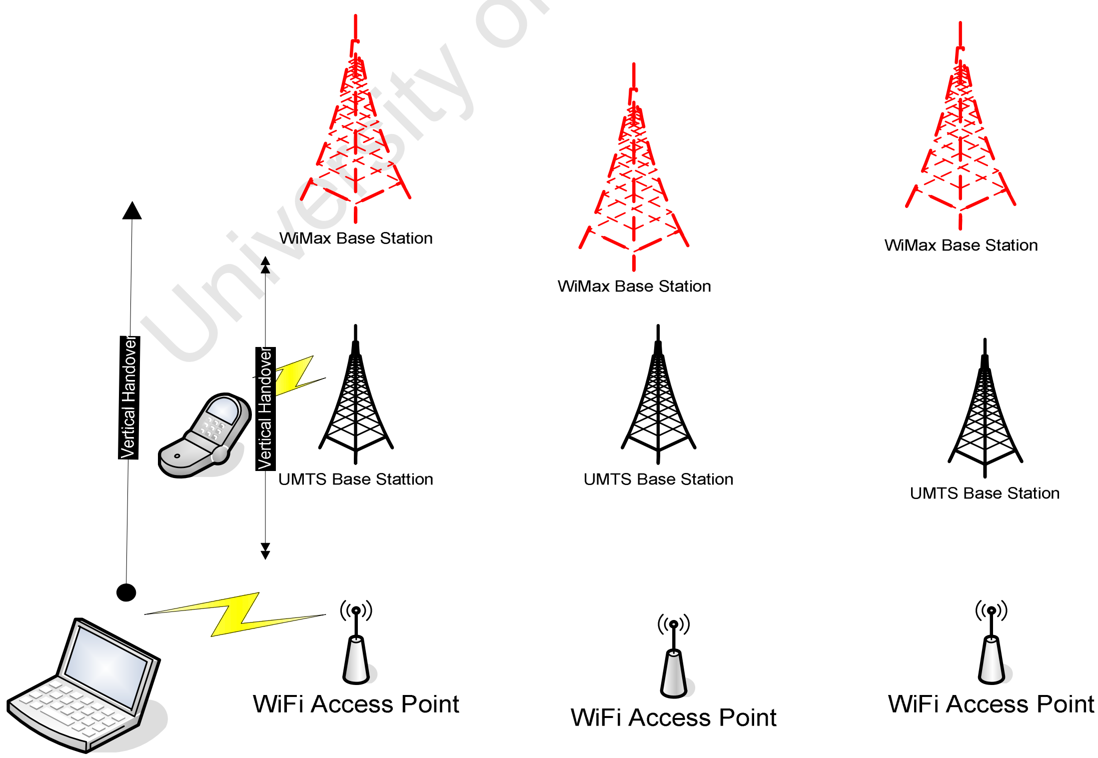

Figure 5. Vertical/ Media Independent Handover

In view of the basic principles discussed in this chapter, our work is aimed at achieving Personal and session mobility, in which access to network services is possible from anywhere and anytime. We believe the ability to achieve to achieve this is dependent of crossing the network boundaries in the heterogeneous overlay networks. We also classify our work under the vertical handovers and macro mobility. Our implementation of the media independent handover function services is aimed at achieving a soft handoff type of handoff as opposed to hard handoff.

3.2.1 Media Independent Handovers

The future of network access points to pervasive and ubiquitous services access demand by clients [45]. This inevitably calls for the integration and interworking of existing and overlaying available networks to afford the user always on connection and access. This is despite that the network of choice and or subscription may not be available at all points that the user requires a connection. Heterogeneous networks access is already being researched all over the world as a key to the ubiquitous and seamless access for a user with an appropriately equipped device [44]. Such devices may be equipped with multiple network interfaces and may, operate them one at a time or possible simultaneously if associated' networks are available and needed for a connection. Another possibility, which is increasingly becoming favourite approach, is that the device may utilise a Software Defined Radio (SDR), which may be extended to operate as a Cognitive/ Adaptive Radio [29] [30] so that even for smaller devices that cannot accommodate many network interfaces this access is still a reality.

The IEEE working group 802.21 has been working on proposing a standard for the media independent access by mobile or stationary users that have the capability of accessing the different network that it is capable of detecting. The standard proposes a protocol stack and specification for Media Independent handover. We model our solution design based on the 802.21 standard drafts. Thus we examine the 802.21 standard proposal.

3.2.2 Media Independent Handovers Overview

The future of communications points to an integrated and interworking of already existing and yet to come technologies. Overall the combination of overlay wired and wireless networks are expected to give the best possible coverage or network access, to fulfil the anytime and anywhere access through the any network concept. The existing wired and wireless technologies are characterised by use of different media technologies with different specifications as has already been shown in the paragraphs preceding this one.

Thus as already indicated the IEEE802.21 working group is working on the standardisation of different media access by a Mobile Node that has the necessary interfaces whether software or hardware. Central to the IEEE802.21 working group's efforts is the introduction of the Media Independent Handover Function (MIHF) into the standard protocol stack. As of May 2008 they have released Draft version 11 of the proposed standard [28]. We base most our arguments on this draft version.

3.2.3 Media Independent Handover Function

The MIHF is logical entity that is placed in between the Data Link layer and the Network Layer of the Open Systems Interconnection (OSI) 7 layer standard [28]. The general diagram of the logical structure of the MIHF is shown in figure 6. Messages are sent from the upper layers to the MIHF and from the lower layers to the MIHF through 3 distinct services. These are the Media Independent Information Services (MIIS), Media Independent Event Services (MIES) and Media Independent Command Services (MICS) [28]. Figure 6 gives an overview of the MIHF and its services in relation to its adjacent OSI layers. From the upper Layers these come through the Network Layer Service Access Point (SAP) and from the lower layers they come through the Link Service Access Point (SAP). Specifically through the MIH_LINK_SAP and the MIH_SAP the MIHF communicates with the Data Link and the Network Layer, respectively.

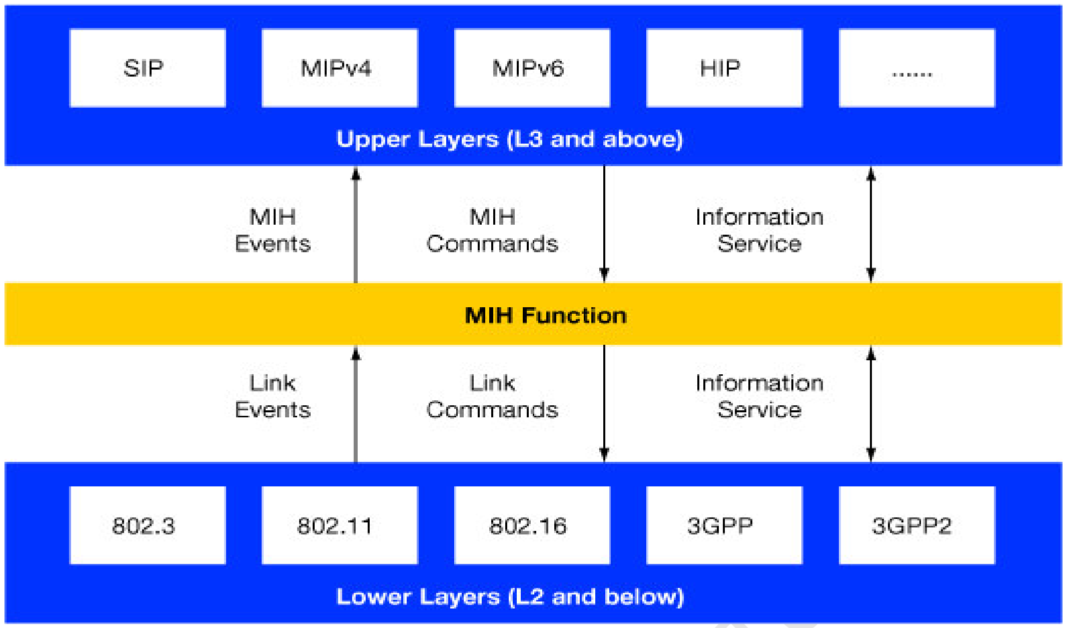

Figure 6. Media Independent Handover Protocol stack Architecture [50]

(Source: Media Independent Handovers Tutorial, available http://ieee802.org/21)

3.3.1 Media Independent Information Services

MIIS provide information on the characteristics of and services provided by the serving and neighbouring networks. MIIS also provides a framework and assisting mechanisms for a node implementing MIHF to discover, obtain network information of networks that exist in a geographical area thereby facilitating network selection and handovers [28] [51].

MIIS uses a set of information elements (IE), with a certain type of information structure and representation, as well as a query and response interaction for information transfer. The information can be stored in an information server, such as a Third Party broker, from where the MIHF in the MN can access it. Information is communicated to the MIHF through the adjacent layers' Service Access points (SAP).The information structure normally takes the format of Type Length Value (TLV) packets, defined as a schema. MIIS specifies a common (or media independent) way of representing this information across different technologies by using a standardized format such as extensible mark-up language (XML) or binary encoding. MIIS information exchange is different from the push model of information transfer for the event service, which is non-interactive.

The information that can be obtained may contain 3 types of information elements depending on the specified query. These elements may be general information and access information, point of Attachment specific information and vendor/network specific information.

Table 3 (a). General Information elements

Information Element	Description
IE_NETWORK_TYPE[12]	Types of the access networks available in a reception area/cell.
IE_OPERATOR_ID[13]	Network operator identifier for the access network/core.
IE_SERVICE_PROVIDER_ID	Service provider identifier.
IE_COUNTRY_CODE	Country identifier

Table 3 (b). Point of Access Information Elements

Information Element	Description
IE_POA_LINK_ADDR[14]	Link layer address of PoA
IE_POA_CHANNEL_RANGE	Channel Range/Parameters. Spectrum range supported by the channel for that PoA
IE_POA_SYSTEM_INFO[15]	System information supported by the link layer of a given PoA

MIIS provides information on static link layer parameters such as channel information, MAC address and security information of a network point of attachment. Information about available higher layer services in a network can also be used to assist in the network selection and handover decision, before the MN actually attaches to any of the available networks..

IEEE802.21 MIIS provides the ability to access information about all networks in a geographical area from any single L2 network, thus the possibility of implementing a Third Party to play this role is inherently catered for in the standard. Typically, in a heterogeneous environment with networks implementing different media architectures, the network selector module uses information from different media types to select a network and effect its handover decision. Thus with the use of the MIH standard, power concerns are taken care of as the MN does not have to power up all available interfaces to discover the resources available on the nearby networks using different architectures from the serving network. Only once the decision on which network to attach to, may the MN activate the appropriate network interface or reconfigure its software radio.

Table 3 (c). Access Network Information Elements

Information Element	**Description**
IE_NETWORK_ID	Access network identifier.
IE_NETWORK_AUX_ID	An auxiliary access network identifier e.g. in IEEE 802.11 this refers to the homogenous extended service set ID (HESSID).
IE_ROAMING_PARTNERS	Roaming Partners that network has contracts with
IE_COST	Cost Information
IE_NETWORK_QOS	QoS characteristics of the link layer
IE_NETWORK_DATA_RATE	The maximum value of the data rate supported by the link layer of the access network.
IE_NET_FREQUENCY_BANDS	Frequency bands supported by the network.
IE_NET_IP_CFG_METHODS	IP Configuration Methods supported by the access network
IE_NET_MOB_MGMT_PROT	Type of mobility management protocol supported
IE_NET_MOBILE_NETWORK	Indication of whether the access network supports mobility.

3.3.2 Media Independent Event Services

Media Independent Event Service (MIES) provide event classification, event filtering and event reporting as changes in link characteristics, link status, and link quality occur [28].

Events that can lead to handover may be related to MAC, PHY or MIHF changes in the MN, or the network. MIES is subscription service, implying a MN has to subscribe to receive event notifications from a particular event source. The MIHF distributes these events to interested layers and according to subscription. Event notifications are generated asynchronously.

Fundamentally these events are advisory in nature and not mandatory. Thus the MN is not forced to act on events notifications. The Event Service is divided into two categories, Link Events and MIH Events. Link Events are events that originate from event source entities below the MIHF and terminate at the MIHF. MIH events are events that originate from within the MIHF, and they may be Link Events that are propagated by the MIHF to the MIH Users. The general flow of events messages is shown in figure 7 and Table 4 shows the MIH Events.

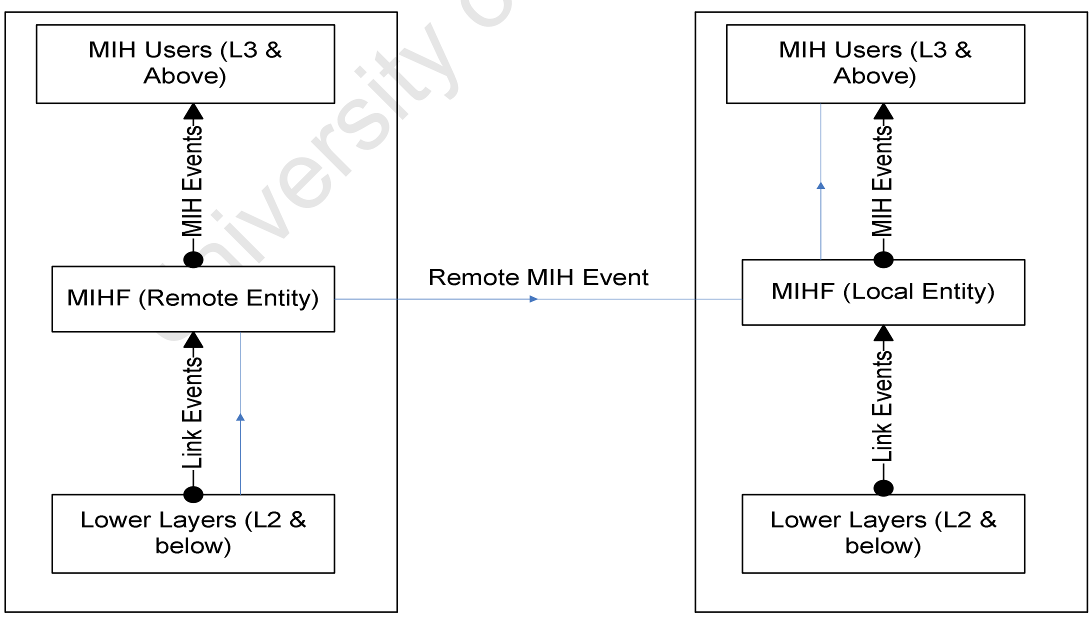

Figure 7. Link and MIH Events stack flow

Figure 7 shows the Link and MIH Link Events, protocol stack. Link events in a remote entity are passed on to the Remote Entity's MIHF, which is responsible for transmitting to its peer MIHF in the Local Entity. The MIHF in the local entity will then pass the event information to the upper layers (MIH Users) to analyse and decide on the course of action. This may result in issuance of a MIH Command. For example, a link event such as Link_going_down, sent to the MIHF, prompts the MIHF to send out a MIH_Link_Going_Down to the Local entity. Once the local entity receives this at its Upper layers via its MIHF, it may initiate a MIH_MN_HO_Candidate_Query to query candidate networks for handover and sequential issue commands until a handover has been completed marked by a MIH_Link_Handover_Complete.

If handovers have been committed too hastily, and the mobile node's reception of the former serving network improves, there may be an event rollback. An event rollback leads to the mobile node switching from the handover Point of Attachment to the original PoA. Thus an optimal threshold of events needs to be determined to push the MN to initiate handover.

3.3.2.1 Link events subscription

During initialization the MIHF actively searches for pre-existing interfaces, devices and modules that serve as link event sources in the Event service. In addition to the link event source entities that are present during the bootstrapping stage, allowances are made for devices such as hot-plugged interfaces or an external module. The MIHF subscribes individually with each of these link layers based on user preferences.

3.3.2.2 MIH events subscription

MIH Users specify a list of events for which they wish to receive notifications from the MIHF. For an MIH event that can originate both locally and remotely, an MIH User specifies whether it is subscribing for the local event only, remote event only, or both (which would require two separate subscriptions). If the MIH event that an MIH User wants to subscribe to is not supported or is not available, then the MIHF rejects the subscription request and notifies the MIH User accordingly

Table 4. MIH Events

MIH Event	**Description**
MIH_Link_Parameters_Report	When Link parameters have crossed a specified threshold and need to be reported.
MIH_Link_Going_Down	Link conditions are degrading and connection loss is imminent.
MIH_Link_Detected	Link of a new access network has been detected. This event is typically generated on the MN when the first PoA of an access network is detected. This event is not generated when subsequent PoAs of the same access network are discovered
MIH_Link_Handover_Imminent	L2 handover is imminent based on either the changes in the link conditions or additional information available in the network
MIH_Link_Down	L2 connection is broken and link is not available for use.
MIH_Link_Up	L2 connection is established and link is available for use.
MIH_Link_Handover_Complete	L2 link handover to a new PoA has been completed

3.3.3 Media Independent Command Services

Media Independent Command Service (MICS) is the MIHF service that allows for commands to be sent to/from MIH terminals/nodes. MIH nodes use command services to control the behaviour of the MIH nodes that it communicates with. Using information provided by MICS and in conjunction with events as pushed by the MIES, commands are issued to effect handovers, selection etc .A number of commands are defined in IEEE802.21 standard to allow the MIH Users to configure and control the MIH nodes [28]. An MIH command is acknowledged by an MIH indication as shown in figure 8.

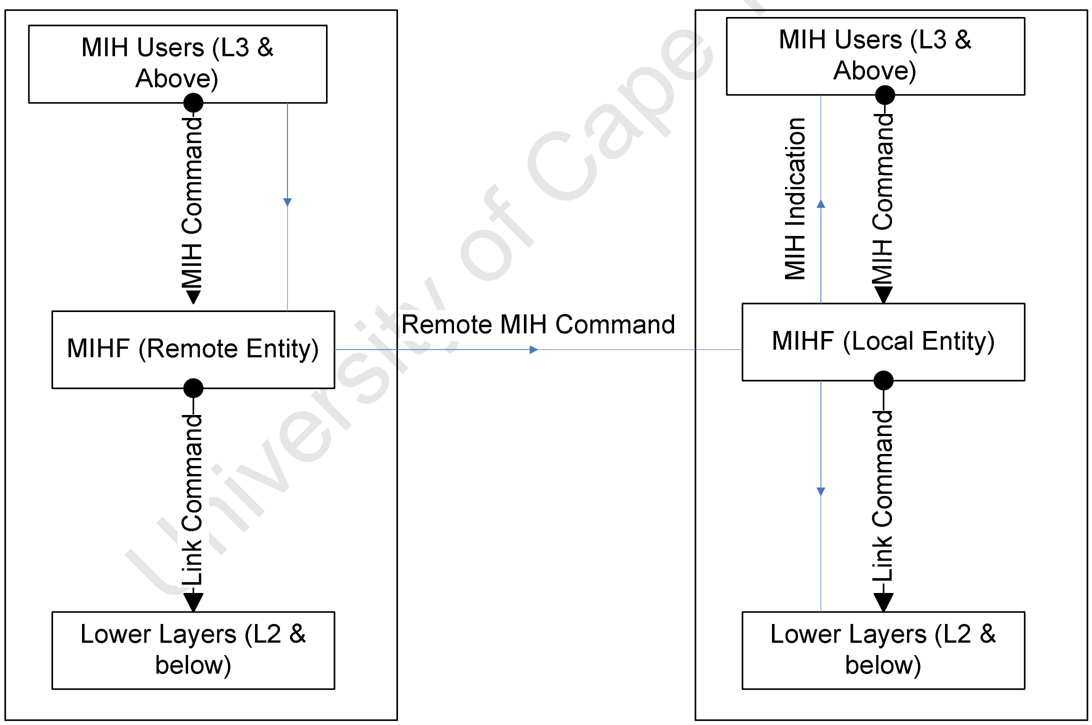

Figure 8. MIH Commands stack flows

MIH commands are issued by MIH Users i.e. Upper Layers, such as the Application Layer of the protocol stack. They are issued to the MIHF which passes them to the Lower Layers for action. These commands may e.g., the Link the configuration parameters and thresholds.

Table 5. MIH Commands

MIH Command	Description
MIH_Link_Configure_Thresholds	Configure link parameter thresholds
MIH_Link_Get_Parameters	Get the status of a link
MIH_Net_HO_Candidate_Query[16]	In Network (Net_) initiated handover, this command queries a list of suggested networks and associated Points of Attachment to MN.
MIH_MN_HO_Candidate_Query	Command used by MN to query and obtain handover related information about possible candidate networks
MIH_N2N_HO_Query_Resources	This command is sent by the serving MIHF entity to the target MIHF entity to allow for resource query. This is a Network to Network (N2N) command
MIH_MN_HO_Commit	Command used by MN to notify the serving network of the decided target network.
MIH_Net_HO_Commit	A network issued command for which the network commits to do the handover and sends the choice of selected network and associated PoA to the MN.
MIH_N2N_HO_Commit	Command used by a serving network to inform a target network that an MN is about to change over to that network, initiate context transfer (if applicable), and perform handover preparation.

In this chapter, we examined the core of our proposed solution to network selection problem in heterogeneous networks. We discussed the implementation of the Media Independent Handover Function, which assists in network discovery, network selection, handover initiation and handover operation in heterogeneous networks. The policies that utilise the services of the MIHF to carry out network selection can be implemented in the MN or the network, however the co-operation between the two is very important for an effective selection process.

Chapter 4

4.0 Heterogeneous Networks Selection

In the next generation networks, the user driven service access, from anywhere, anytime and any network, shown in the figure (9) will demand a high level of co-operation between the network and the mobile user or stationary user who intends to switch over to a new network which is not necessarily the home network.

More challenges in authentication, security, Quality of Service (QoS) and billing areas are also anticipated as the user may not be required to make special prior arrangements such as exist for international roaming users, as we know it to date. The more networks available at any on particular point or reception area, the more difficult it could be for the mobile user to select the best network to use, especially in meeting the delay and QoS requirements of the application currently running, by mobile user.

4.1 Network Selection Overview

Traditionally subscribing users have a default network that their devices always seek to connect to. Despite the availability of several networks in the area, failure to identify and connect to the home network in this scheme leads to device indicating that there is no network coverage/detected. In the legacy network that have always existed and the devices developed earlier, the actual existence of the other networks may actually be totally out of the capability of the devices as they may manufacture to use different resources such as frequency spectrum and modulation schemes. In the event of the same spectrum and modulation schemes being used, this may be a case of network ID and authentication, which has failed the connection whereas the existence of the network is detected.

In the Home network Default (HND), the user device has all the information it needs to seek its home network an is given an authentication key that it supplies to get access to network services available to it according to subscription details in the system.

Always Best Connected scheme is based on decision by MN and applications that the MN is running [14] [15]. This type of scheme generally gives the best throughput as the network to connect to, is picked due to available resources. If optimal measurement schemes are employed the MN may disconnect and reconnect to a network as the need arises, e.g. when running a simple voice call the MN may connect to a 2G or 3G networks available and change to 802.16 when it needs more bandwidth and there is no 802.11 network available especially when running bandwidth intensive data applications. If while still running the same application it detects a higher bandwidth network like 802.11 networks, it may also change to the new detected one. However, the Always Best Connected scheme normally does not take into account the cost of connection to the best available network for its application.

In contrast to the ABC, the Price based connection scheme is mainly concerned with the cost [13] of using the network available and may compromise on the quality of service offered just to meet the cost involved

Other schemes employable include Signal strength based [31] [41], which will opt for the network with the best detected signal and ignore other factors such as cost and resources available, this mostly for applications that require constant connectivity.

Random Connect which may also be the same as whichever connects first. Normally the best for emergency call scenarios as the idea is to quickly transmit information. Emergency call numbers such as 112 use this type of scheme and get priority in the allocated channels of the network for routing the nearest termination point [32].

Compatibility & Network Operator Agreements- which operate more like roaming agreements[15] and normally mean exchange of subscriber information and a standard agreement to users crossing into each other's network. Such agreements may also be prompted by compatible equipment in use or relatively equal sized networks such that there is no exploitation of the other network should such an agreement exist between different sized networks in this type of arrangement prior information may be supplied to the user of feed to MN.

Application or QoS Based[33] connections are similar to the Always Best Connected (ABC) schemes, however they offer flexibility in that they can take a lower rated network connection, in terms of resources as long as the application running will get it required QoS. This may be while a higher rated network connection is available is determined to be a waste of resources in the light of the application. For example an application such as voice call does not need the 54Mbs offered by the WLAN but can use the 64Kbs offered on GPRS network if packet based billing is required. This type of scheme may result in several connection changes as the need arises or several simultaneous connection as other application start running and their needs are different from their predecessors.

Our investigation, typically extends most of the described network selection schemes, but seeks to move away from schemes such as the Home Network Default and Compatibility and Agreements schemes. This is because our initiative is to free the user from being restricted by defaults and agreements. Dynamic and pro active selection for the next generation networks is our vision of network access. Thus while a user subscribes with a particular network provider, if at a certain moment their needs are best addressed by a different network where no prior arrangement has been made for access, the user should still be able to select and use that network. Generally, our work resembles the ABC scheme with a defined standard approach, which relies on user preferences. Hence if the preferences are very simple and possibly favouring one aspect such as Cost, then the scheme can also be viewed as a Cost Based in this case, or any other factor as preferred.

4.2 Unassisted Network Selection

In this configuration, the mobile user will interrogate all detected networks for information the network capabilities and specific concerns such as cost and authentication/ security. Theoretically, this method incurs a lot of delay, as the mobile user has no prior information concerning the other available networks or its own serving network's limitations. Thus analogous to the break before make handover in cellular networks, the mobile user is only prompted to seek another network when serving network link goes down. In a power saving mode, the activation of other radio interfaces for a multi-interface terminal, is another delay inducing activity. For non-real time traffic such as web browsing, the effect of this delay may be minimal but for real time traffic such as voice, the delay would be unacceptable and may lead to disconnection of the call. Otherwise to speed up the selection the mobile node would have to activate all interfaces simultaneously which will lead to high power usage. If software defined radio is in use then interrogation of networks may be one after the other which will introduce an unacceptable delay as the number of networks scales.

4.3 Assisted/Brokered Network Selection

Assisted configuration, for network selection, may entail a broker or pre–informed decision on the network to select, thus implying that the mobile user spends less time in deciding which network to select [45]. In the example of a mobile laptop, the existence of an Ethernet network may be difficult to detect unless prior knowledge is available, as compared to WiFi networks, which advertise their presence through wireless means. Assisted Network Selection may avail such information to the user who will then connect to such a network if deemed better than the wireless networks.

The benefits of using brokers to date in network access have been widely investigated. Brokers assist in several ways to ensure seamless interaction of client and network entities, such as authenticate both entities if both are registered with the broker but have no knowledge of each other. In our envisaged architecture a broker can play a very important role of supplying software drivers to a multi interface node e.g. with a newly plugged Universal Serial B (USB) interface or new set of program instructions for a software radio to access a new encountered network with parameters that the MN has not encountered before. Brokers can also provide a standard price platform between network providers and thus further reducing delay in seamless connections.

4.4 MIH (802.21) and Brokered Network Selection

IEEE802.21 MIH standard defines the information that helps in network discovery and specifies the means by which such information can be obtained and be made available to the MIH Users. The network information includes information about link type, link identifier, link availability, link quality, etc. Network selection is the process by which an MN or a network entity selects a desired network from the available networks. The decision to select a particular network may be based on various criteria such as required QoS, cost, user preferences, or the network operator's policies.

The process of network selection may be assisted or not and normally involves the mobile node consulting either its own policies e.g. such as configured on SIM card or consulting the network or another entity with the knowledge of the available networks. The process of selection and handover initiation may also be started by either the mobile node or the network depending on the existing configuration. In the case of the network initiated handovers, the network selection policy function resides on the network. The network uses the set of "MIH_Net_HO" commands in conjunction with "MIH_N2N_HO" commands for initiating handovers. The network can use a set of commands to query the list of resources currently being used by the MN, so that the serving network can reserve the required resources at the candidate target network. The network can command the MN to commit to a handover to a selected network.

If MN initiates the handovers, the network selection policy function in this case resides on the mobile node. The MN uses the set of "MIH_MN_HO" commands when initiating handovers. The MN uses a set of commands to query the list of available candidate networks, as well as reserve required resources at the selected network.

The MIH standard allows for information about all existing networks in the reception area to passed to the MIHF entity through one network and therefore one interface. Only once the selection process has been completed, is it necessary to activate the appropriate interface. The MIH assistance works well with the multi interface node as well as software defined radio.

In this section, we have given an overview of the network selection scenarios in heterogeneous networks environment and the possible approaches to carry out the selection. Existing and other literature network selection means are discussed to give an appreciation of the process and its drivers. The discussed scenarios and approaches assist in our design architecture, which we discuss the chapter 5.

Chapter 5

5.0 Media Independent Network Selection Design

In real life nodes, network access is realised through a number of steps. Most of these steps are assumed in simulations and quick results of near real environments are obtained. In general, a node on power up goes through self-test routines that take stock of the available network interfaces and checks if they are functional as well as that the node system has the appropriate drivers to operate the interfaces. If the interfaces test ok, then next step is to scan for the availability of the associated networks. If networks are discovered, an attempt to associate with them by SSIDs and network prefixes is the next step. Once associated the node will obtain the necessary information for it connect to the target network. These may include the authentication needed, the DHCP or pre-configured addressing settings and how billing would be handled. Using the appropriate or the available authentication settings, the node will then proceed to initiate a network connection.

5.1.1 Homogeneous Networks Access Design

Our approach is traditional data networks oriented as opposed to the traditional cellular networks, hence our assumed starting point and home network is a WiFi network [34].

1) Network scanning: This leads to network discovery

2) Discover AP/Access Network Capabilities: Querying of the discovered networks resources and comparison with its own requirements or specifications e.g. 802.11a/ 802.11g

3) Connect to the AP: Steps to connect including authentication etc, and if a success then connection is established

4) Transfer and Receive Data: Running of Applications.

5.1.2 Heterogeneous Network Access Design

Our approach is traditional data networks oriented as opposed to the traditional cellular networks, hence our assumed starting point and home network is a WiFi network.

1) Network scanning: This leads to network discovery

2) Discover Access Network Specifications: Querying of the discovered networks specifications such as alluded in earlier chapters such as the physical and MAC specifications and comparison with its own specifications and drivers.

3) Reconfiguration/ Drivers acquiring: Change of software or hardware radio in use. Or attempt to obtain the drivers necessary to function with the available media detected.

4) MIHF connection: Activation and establishment of communication of the MIHF in both the mobile node and network.

5) Connect to the Network: Steps to connect including authentication etc, and if a success then connection is established

6) Transfer and Receive Data: Running of Applications

5.1.3 Third Party and 802.21 Network Architecture

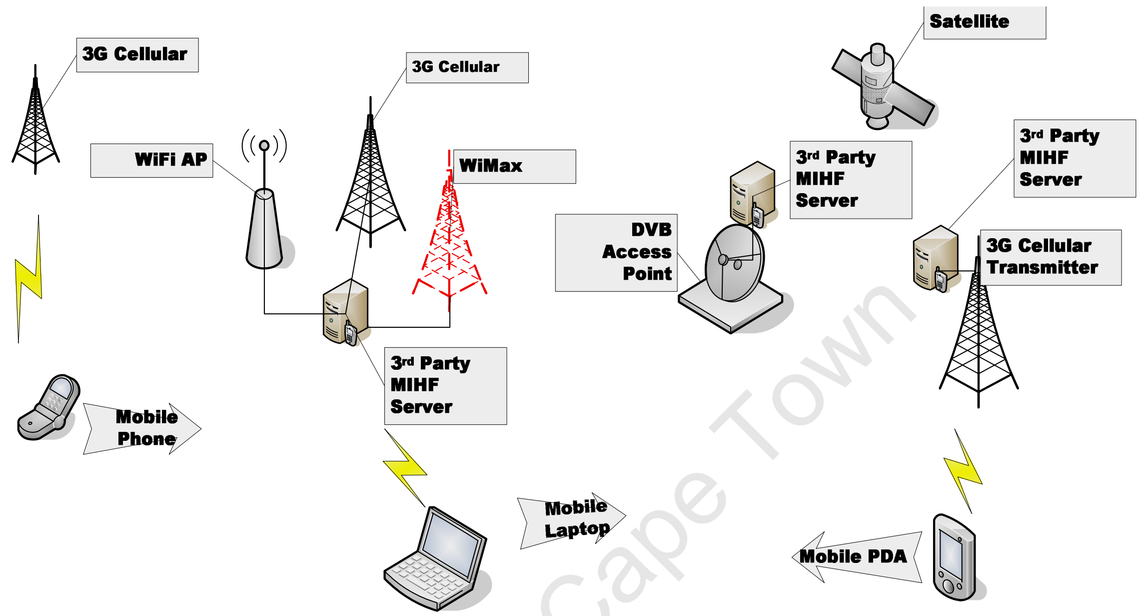

Figure 9. Heterogeneous Networks Access

5.1.4 Media Independent Network Selection Simulation Scenarios

Network selection for a mobile node operating in a heterogeneous environment can be triggered by several events. In this thesis, we examine some of the scenarios that can lead to MN executing a handover to a network selected amongst those available. In legacy systems, handover is mostly a Received Signal Strength Indicator driven event but in heterogeneous networks access network handover may occur even when the MN is not moving at all and RSSI is still excellent e.g., when a cheaper network such as an 802.11 network is suddenly powered up and becomes available.

Thus, Network Selection can occur for the following scenarios

- Boot up & no home network

- Network Deterioration -lower RSSI, Power, QoS etc
- New Link detected
- New Application running
- Mobile user or Stationary

5.2.1 Functional Design based on MIP and MIH

The functional and operational design of our architecture is described in the following paragraphs. A node capable of implementing the basic mobile IP protocol is our design and simulation basis. Thus, our node has at all times at least one IP address, with which it communicates with the internet. In the home network and subnet, the node uses its original allocated IP address. In a foreign subnet or network, the node uses a care of address and its home address as described in the MIP standard. In our architecture, the mobile node is also capable of implementing the Media Independent Handover protocols. In our simulations we however assume the interfaces in use whether they be physical multiple interfaces or software defined, are already in place.

We examine the functional design in a hierarchical manner, starting with MIP, which the node is capable of implementing well in a homogeneous network environment. The next level in our design is the MIH capability, which allows for heterogeneous network access. The final level in our design is the use of Third Party broker as the networks scale and the need for a quick network selection is high, in order to avoid delays and packet losses during communications.

5.2.2 MIP Configurations

Basic MIP assumes mobility of the accessing node, and thus provides for the node to be able to use a care of address when it not in the home network. Using the Foreign Agent and the Home agent traffic from and to the mobile node is delivered correctly. In our architecture, we extend this functionality to a stationary node, which is changing over to a different network, which is not its home network. The candidate network access node, e.g. WiFi Access point or WiMax Base Station becomes the FA and the home network has the HA.

Further developments in MIP have seen the introduction of Fast Mobile IPV6 FMIP/FMIPV6 [27], in which the node predicts an imminent handover using RSSI thresholds and begins the handover process before the break of the current tunnel. This synonymous to the soft handover in cellular network.

To reduce the delays associated with the tunnelling process of MIP, HMIP is also available, in which instead of binding with the HA, the mobile node performs its binding operation with the serving network gateway is assumed to be located nearer to the mobile node as compared to the HA.

In our investigation we use MIPV6. MIPV6 is widely considered to be the next generation network's IP version due to its numerous advantages such as the IP address range in IPV6, the inherent security and inherent mobility as compared to its predecessor the IPV4

5.2.3 MIH Configurations

In our design the MIH capable node is configured to subscribe for MIH Events such as new network available, link going down, thresholds reached. The MIH node then must initiate a MIH Information retrieval of the new networks or the other available networks. The Network selector uses policies defined in the MIH node to select the best of the available network. Such policies may define the acceptable bandwidth required to run the application or the cost range that the user can afford.

Algorithm and Pseudo Code: Network Selection

Begin

Set MIH_Link_Thresholds

Subscribe MIH_Events

```
Get MIH_Link_Parameters

If MIH_Link_Parameters<Threshold

While MIH_Event

Consult MIH_Node Policy

        If Policy=Network_Change

        Scan_MIH_Networks

        Query_MIH_Networks

        Consult MIH_Node_Policy

        Select_MIH_Network

        Prepare_MIH_Handover

        Execute_MIH_Handover

        MIH_Handover_Commit

Else

        If MIH_Handover=success

        Check if best network selected according to policy

                If network =best

                Continue_Session

                End if

Else

        Consult MIH_Node_Policy
```

Select_MIH_Network

Prepare_MIH_Handover

Execute_MIH_Handover

MIH_Handover_Commit

End If

End If

End If

5.2.4 Network Architecture Design Parameters

Our network architecture design parameters for nodes, base stations and access point used in our NS-2 simulation are given in the following tables.

Table 6. IEEE802.11 Access Points Parameters

Parameter	Value
Data rate (Wireless Uplink & Downlink)	11 Mbs
Queue Type	Drop Tail
Routing	DSDV
LAN B/W (to router & Broker)	100Mbs
Mac Interface	Mac/802_11 (Wireless) 802.3 (LAN)
Cost Factor	Cost_factor_0
Bandwidth Factor	Bandwidth-factor_1

Table 7. IEEE802.16 Base Station Parameters

Parameter	**Value**
Queue Type	Drop Tail
Routing	NOAH
Mac Interface	Mac/802_16 (Wireless) 802.3 (LAN)
Modulation	OFDM_16QAM
LAN B/W	100Mbs
Cost Factor	Cost_factor_1
Bandwidth Factor	Bandwidth_factor_0

Table 8. UMTS Base Station Parameters

Parameter	**Value**
Data rate (Wireless Uplink & Downlink)	384Kbs
TTI Bandwidth Factor	Bandwidth_factor_2
RNC Link B/W	622Mbs
LAN Bandwidth (Broker connection)	100Mbs
Queue	Dummy Drop Tail
Mac Type	UMTS/RLC/AM
Cost Factor	Cost_factor_2

5.2.5 Message flow in MIH Network Architecture

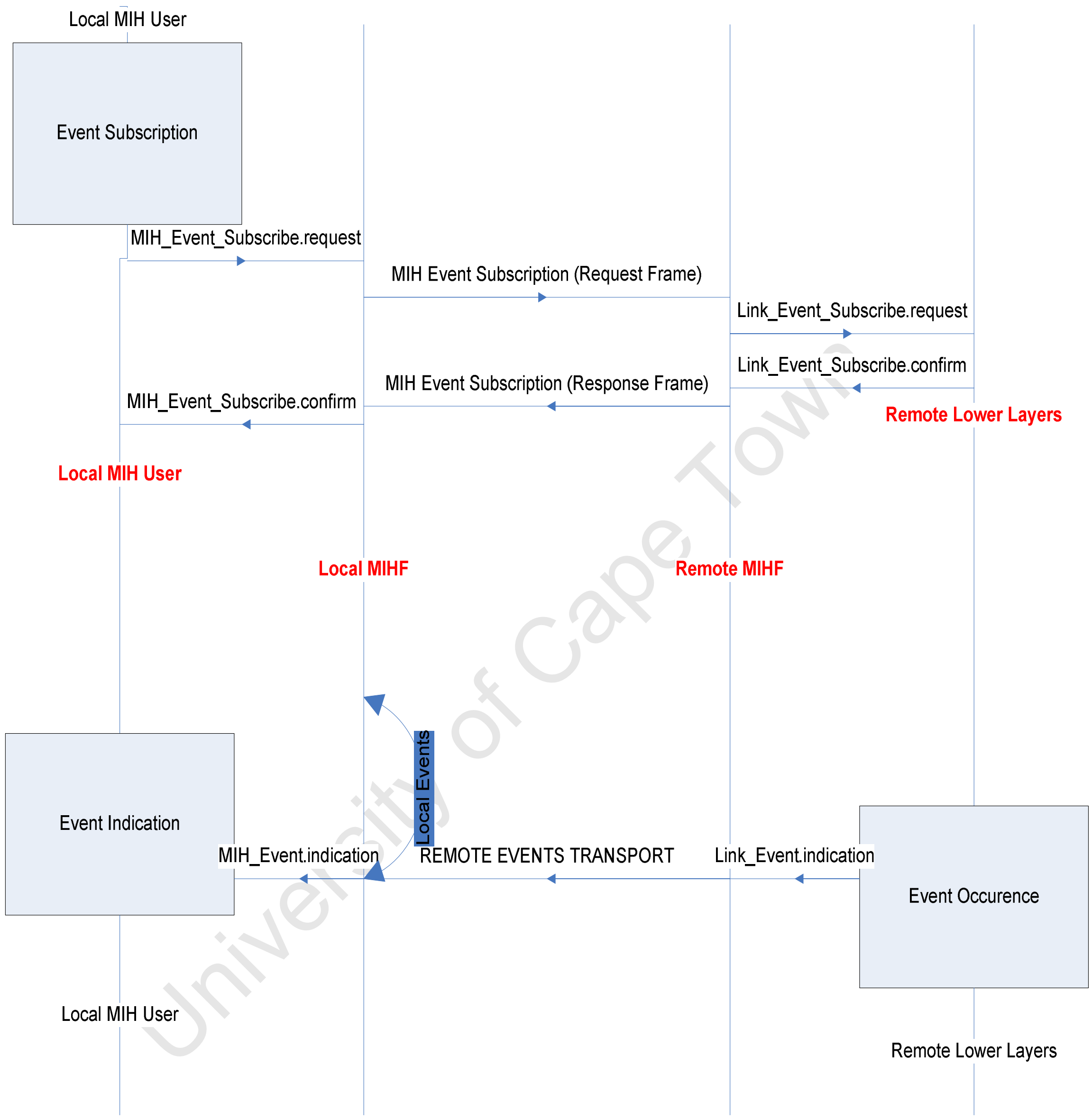

Figure 10. MIH Events subscription and services message flow

The flow of MIH Events messages between a local MIH entity (in our case MN) and remote MIH entity (Network)

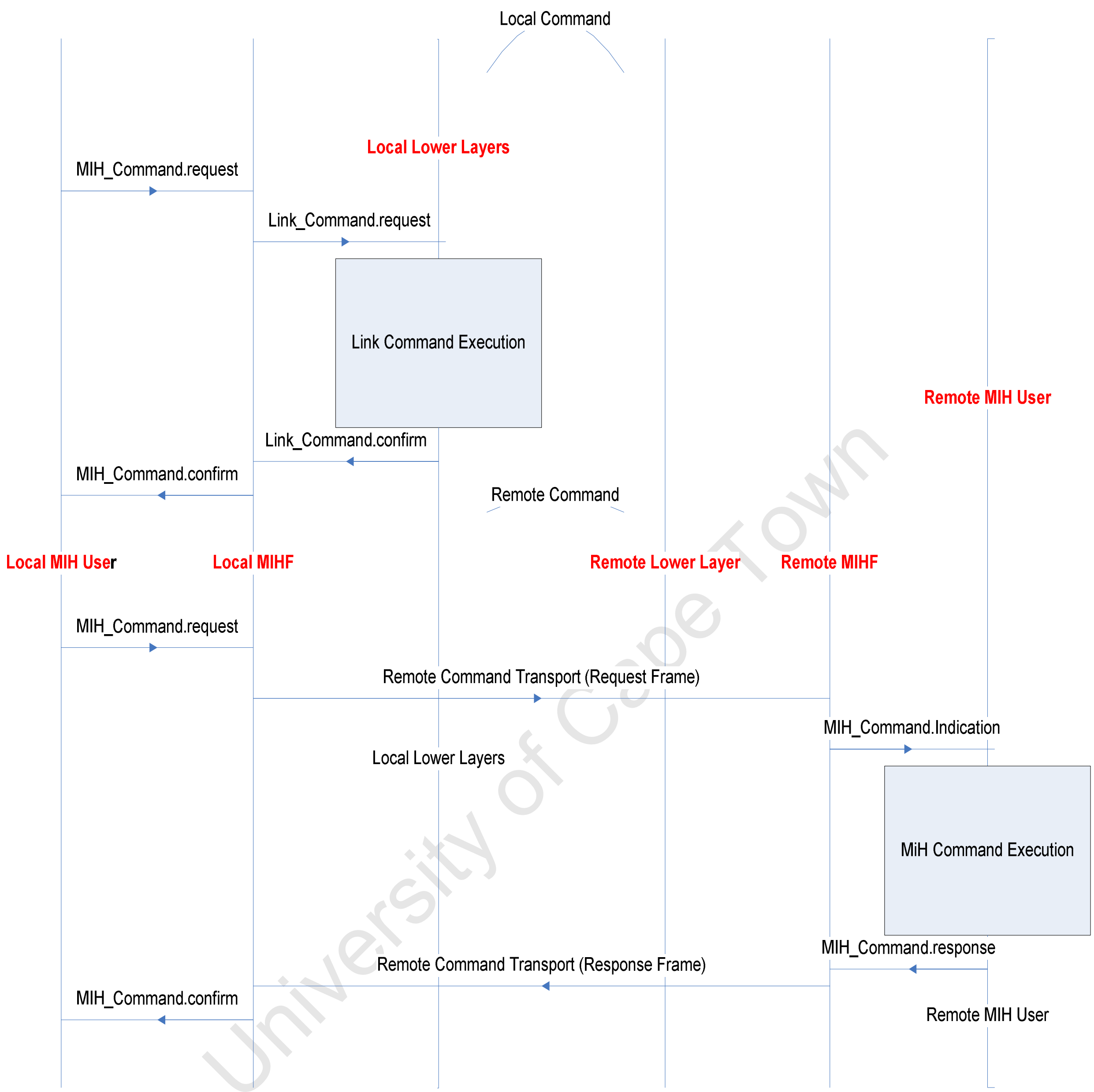

Figure 11. MIH Commands Message flow

Figure 11 shows the MIH Commands Sequence Flow, for a local command sequence such as a MN initiated handover, implying MIH Commands are sent from local MIH users to effect a handover. For remote command sequence, this may be in the case of a Network initiated handover, thus the network issues MIH commands such as MIH_Net_HO_Commit to the MN.

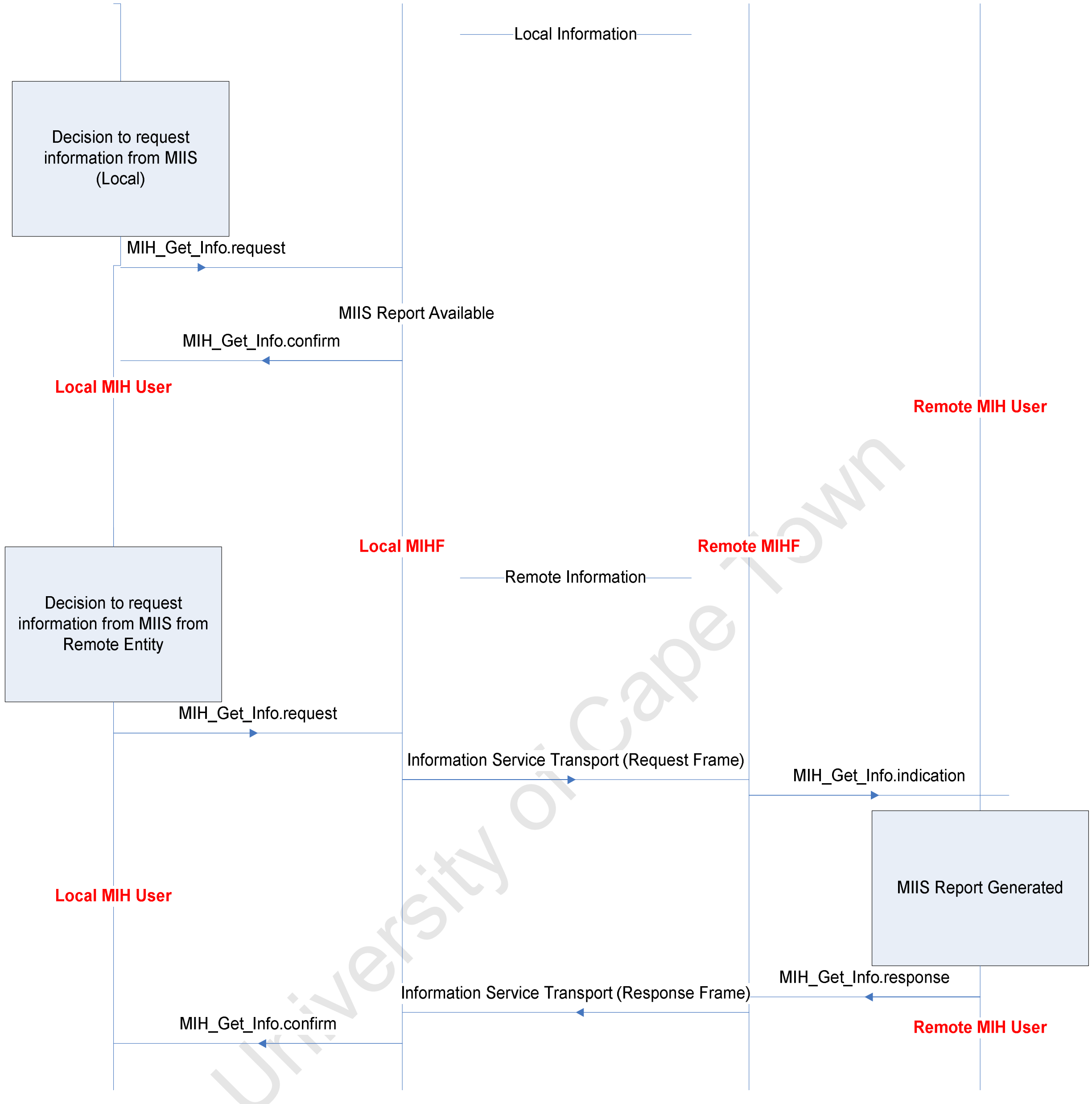

Figure 12. MIH Information Service message Flow

The message sequence flow for the MIIS is shown in Figure 12. Information about Link state, network resources etc is exchanged between the Network and the MN.

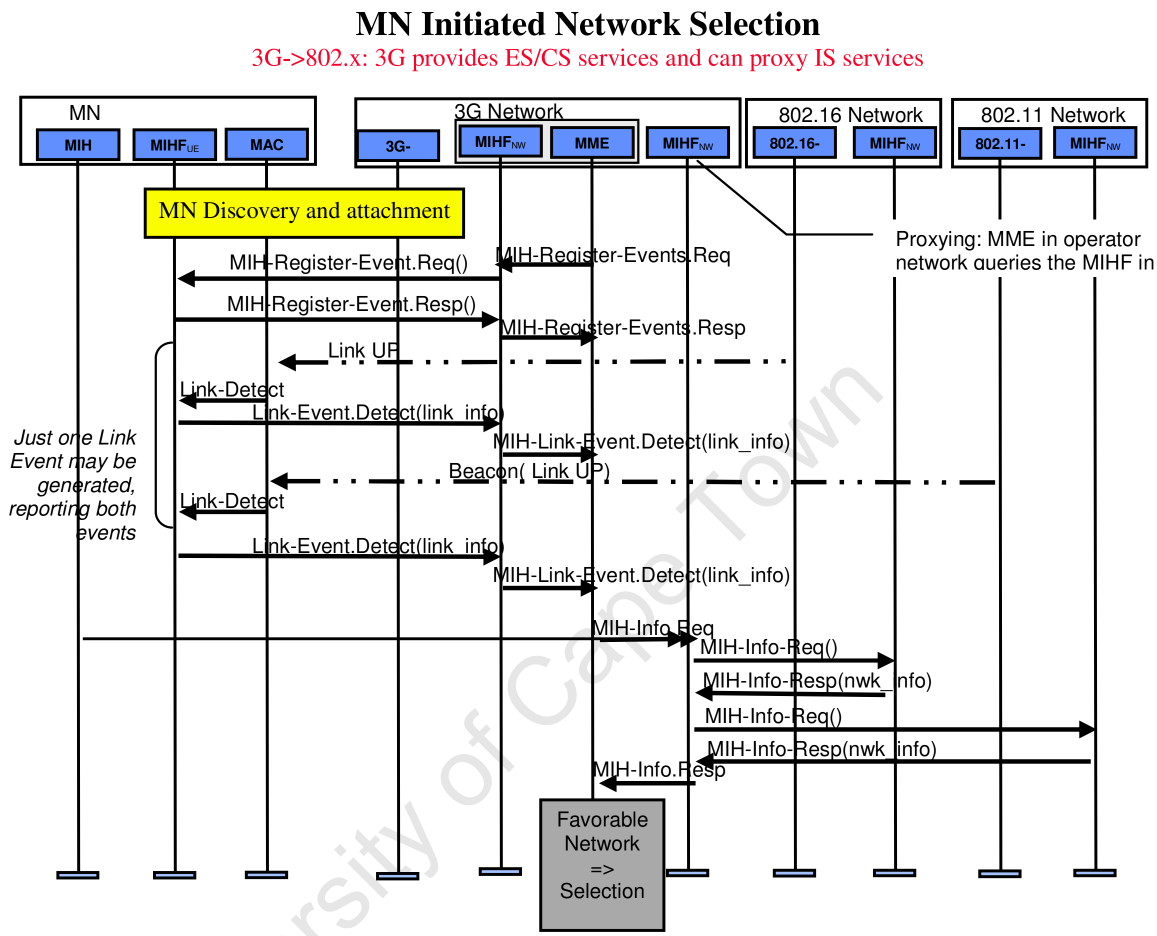

Figure 13. Message Flow in our Architecture

Figures 10, 11, 12 and 13 show the message flow sample in an MIH network. The MIIS, MICS, MIES messages that assist in network discovery, network selection and handover to selected network. Figure 13 is an illustration of our implemented network when a MN whose current serving network is a 3G (UMTS) network is about to handover to an IEEE802.X Point of Attachment.

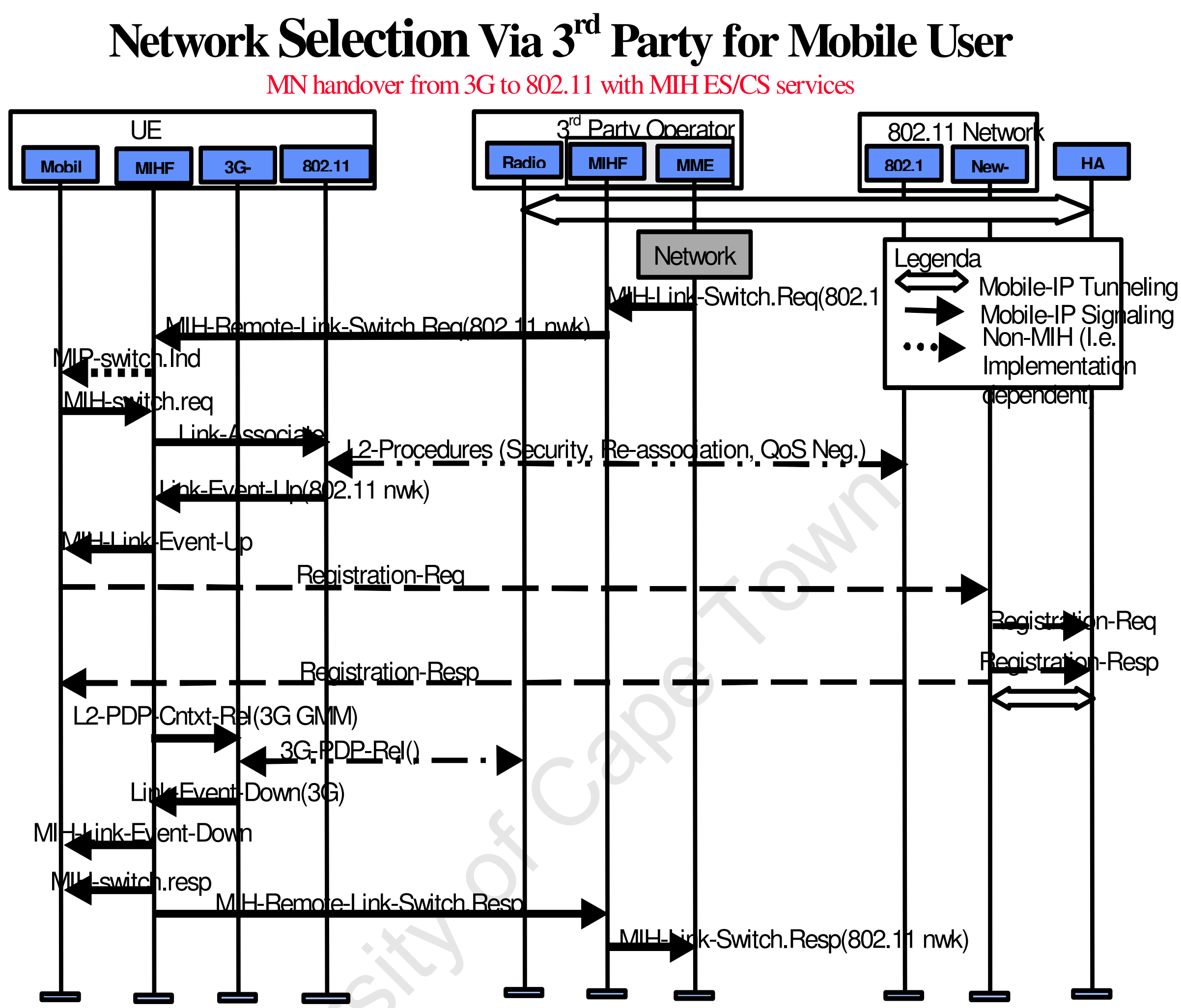

Figure 14. MIH and Broker Involvement

Figure 14 shows the involvement of Broker services, in this case when Network selection and handover is from 3G network to an 802.11 network.

This chapter shows the design used in our simulations to validate our proposal. We examine the control information flow during the network selection process. The simulation and evaluation results are discussed in chapter 6.

Chapter 6

6.0 Simulations and Conclusions

This chapter describes the simulation platform used in the Network Simulator version 2 (NS-2) to support the proposed heterogeneous networks architecture, implementation and results obtained during our research. We also analyse the results and suggest future work in this area of research.

The evaluation framework supports MIP (MIPV6), Fast mobile IP handovers and MIH signalling messages. Non Real-time ,CBR and Real time traffic simulation is supported, and used to illustrate and compare the proposed architecture to the existing schemes, to represent for example a web browsing session (non real time) and a voice call (cbr and real time).

Open source software, Network Simulator (NS) is a discrete event object-orientated simulator, written in C++, with Object Tool Command Language (OTcl) as an interpreter. The implementation of the simulator allows simulation routines at a software level implementation in C++/TCL while OTcl provides the interface to describe the topology of the simulated network. Originally developed by the University of California Berkeley et al, under the VINT project, the NS has gone through several and parallel developments with most features documented in the Ns Manual formerly known as the "NS Notes and Documentation"[35]. We utilise the version 2 of the Network Simulator (NS-2) for our simulations, "the seamless and mobility package" optimised by the National Institute of Standards and Technologies (NIST)'s Advanced Networking Technologies Division [36] [37]. Objects are supported as classes or subclasses of super classes. The core of our proposal, the MIHF extends the class agent defined in Ns-2.

6.1 MIHF Implementation

The generic class Agent in Ns-2 can be used to represent protocols such as the MIHF, TCP, and UDP etc at specific layers or end-points of the network where packets are generated or sink. The class is implemented partly in OTCL and C++. The MIHAgent communicates with the Lower Layers and MIH Users (Upper Layers) as shown in Figures 6-8. The MIHAgent handles a list of interfaces, subscribing MIH Users, remote (peer) MIH Users, active sessions and MIH messages being processed. The MIHF Agent design [37] is shown in figure 15.

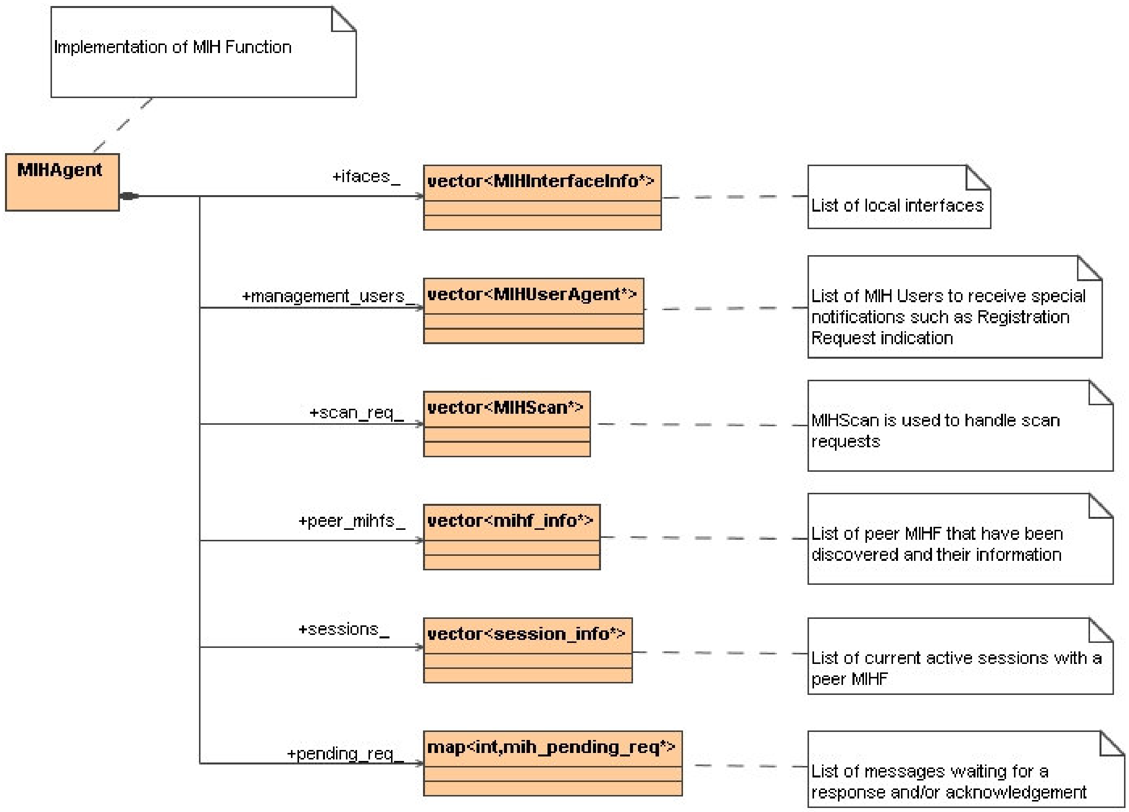

Figure 15. MIHF Design [37]

6.2 MIH User Agents

The MIH User Agent also extends the class Agent (Figure 16). The MIH User Agent registers with the MIHF Agent to receive information, events and commands from the local and remote MIHF. By extending the class MIH User one can implement a custom MIH user to suit the needs and policies of the network or the Mobile Node.

Figure 16. MIH Use Agent Class

6.3 MIH Node

Implemented as a multiFace extension of the class node, the MIH node actually implements several nodes with different interfaces. The other nodes are considered as interfaces of the MIH node. The MIHF keeps track of events and commands on all the interfaces and appropriately redirects traffic to the target interface. Figure 17 illustrate the implementation of a MultiFace Node that is MIH enabled. The Interface manager co-ordinates the interfaces from the different nodes that co-operate to from the MultiFace node. In our implementation an abstract class Network selector- contains the network selection policy used by the MN when encountering several available networks. By comparing the thresholds versus received signal strength (RRSI), bandwidth factor, cost factor and QoS factor and the current running application, the MN can decide on the best network to perform handover of current sessions.

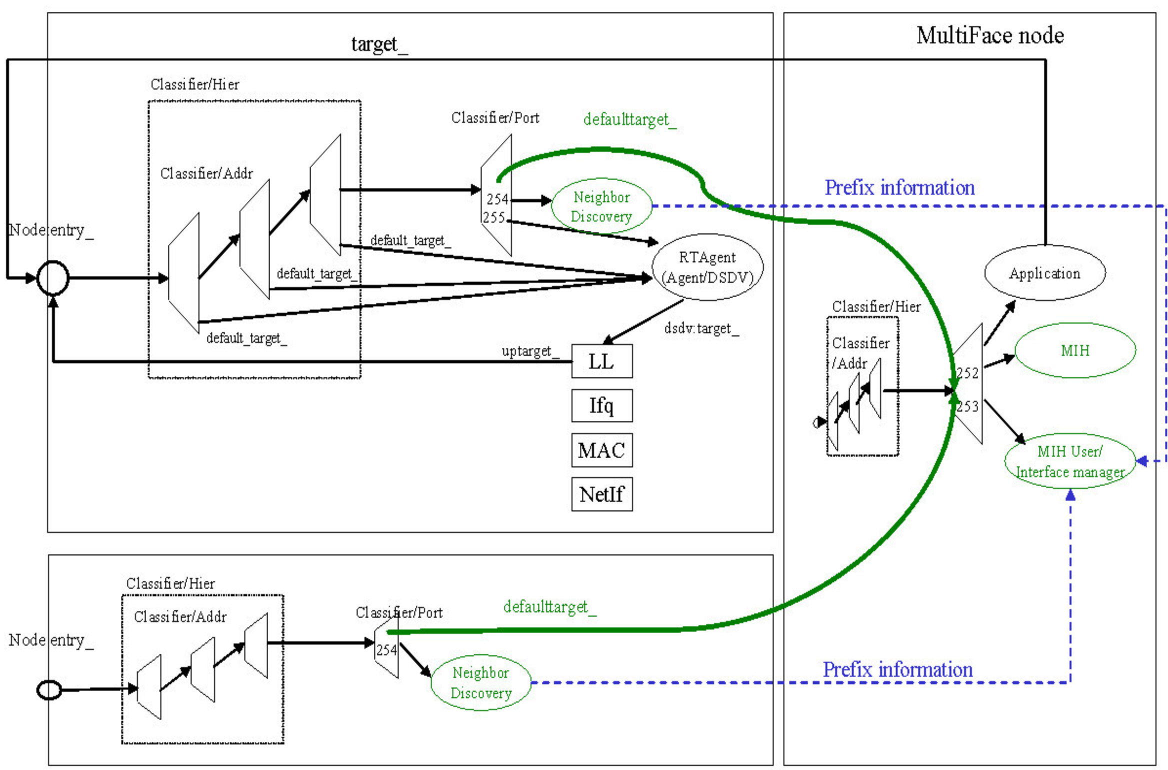

Figure 17. MIH Node Structure in Ns-2 [37]

6.4 NS-2 Simulation Output/Results

Ns-2 simulations can give output in the form of trace files created by such a code

```
#configuring and creating tracefiles
set f [open delay.tr w]
set f1 [open packetloss.tr a]
set f2 [open bandwidth.tr b]
set f3 [open cost.tr c]
$ns trace-all $f
```

The trace files generated during the simulation, the output can be simplified for interpretation using AWK files that extract the required components of the trace file and the interpreted results can be tabulated or represented as graphs for simulated scenarios.

6.4.1 Network Selection Packet Loss and Delay

Using generic nodes to validate our solution, standard IP Packets are attached to802.21 MIHF Agent in NS-2 environment, with same standard parameters in networks nodes, our results that follow show that an 802.21 MIHF and Third Party implementation reduces the delay experienced by the packets.

Using a parameter ping packet to probe the available networks in order of availability with the target network configured to be pinged last before a data packet can be sent .A Time to Live (TTL) setting for packet is unrestricted. The results used are average values and represented in Figure 18.

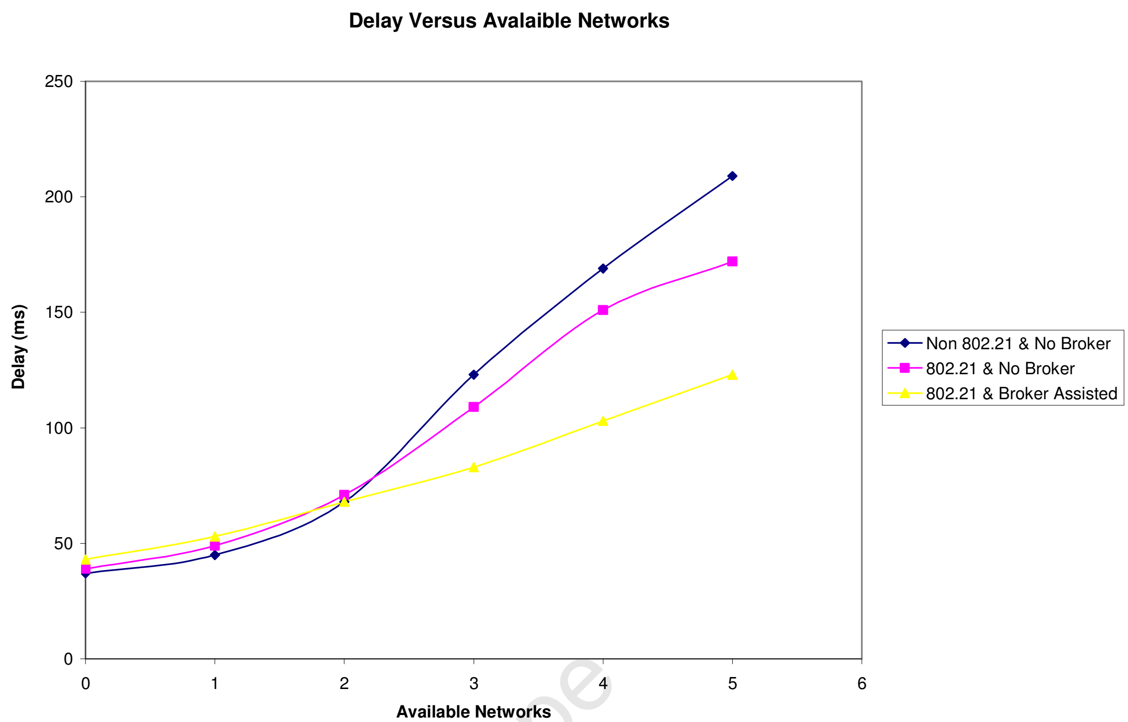

Figure 18. Associated Delay versus available Networks

From our validation simulation, we realise that the performance of the network implementation as a general indication is greatly improved by the use of the MIHF and Broker configuration, in the scale of networks investigated which is between 1 available network and 5 networks, in comparison with a scheme that doesn't employ the services of the MIHF. In Our Validation simulation, we also determine the rate of packet drop by emulating real internet traffic, which has a defined Time to Live (TTL) before being discarded/dropped.

When TTL parameter in the IP packets is restricted to 25ms the delay experienced against the packet drop rate is sketched in the graph Figure 19, indicating a huge packet drop as delay approaches the TTL value when CBR traffic is fed while the mobile node is selecting from more networks available than when there are less. However, the 802.21 and Third Party implementation only begins to experience packet drop when a significantly large number of networks to consider from the Third Party supplied information increases.

In our analysis, the performance of a 802.21 device is better than of a non 802.21 device. However the better performance is seen as the network to select from scale. If only no other network is available other than the target network, the 802.21 device is performs badly compared to the non 802.21 device because of the overhead of MIH messages. The sequential information retrieval for network selection for a non 802.21 introduces an exponential delay as the networks grow and thus this implementation performs badly as networks scale. The solution to this would be to power up the other interfaces simultaneously (which can also be argued to be impossible due to processor queues), and obtain the networks' information in a close to parallel retrieval as possible. The drawback of this approach is the power consumption of the devices at all network selection events, which is avoided by the MIH approach that obtains all available networks via one interface.

The advantage that the MIH 3rd Party node provides is the centralised and cached information, which performs better than the pure MIH implementation. This is because the MIH implementation while it allows all networks information to be retrieved via one interface such as the serving network node, the information is not cached in the serving network. Practically these nodes will belong to competitor networks and this information will be retrieved upon request.

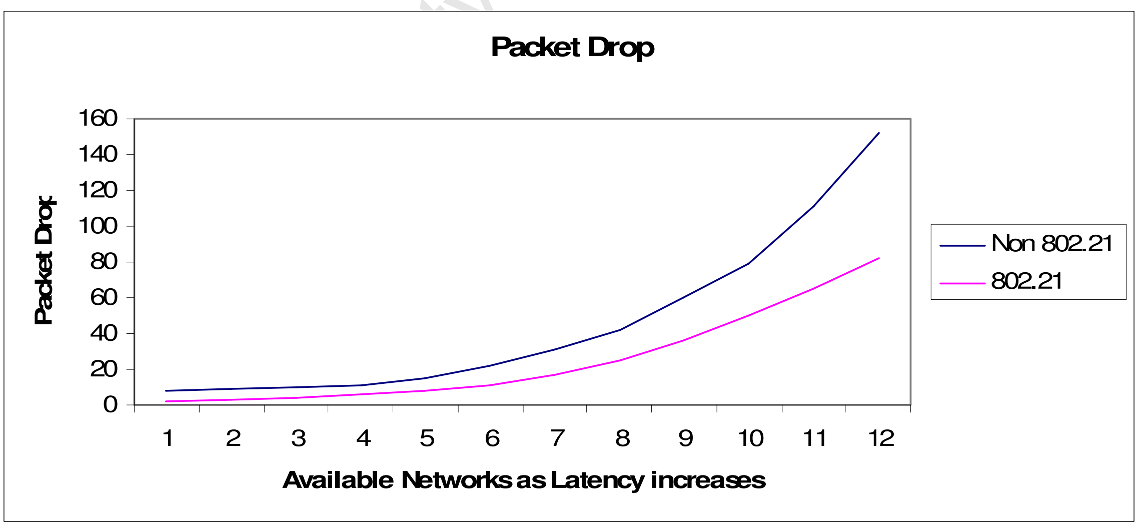

Figure 19. Packet drop versus Latency as number of Networks increases

The analysis of the results is that as the time to decide on which network to select increases, which has been determined to be related to the increase in the number of networks, the amount of packets dropped before they can be delivered increases due to queuing effects in the system.

Having validated our proposed solution we investigated several metrics and scenarios affect or are affected by the network selection process in heterogeneous environment. We use WiFi (WLAN/IEEE802.11) Access points, WiMax (WWAN/IEEE802.16) Base Stations and UMTS (3G) Base Station with simulation parameters outlined in section 5.2.4 of this Thesis. The measurement metrics which use MIH messages make it difficult to compare these results with the 802.21 implementation and thus only the performance of the 802.21 implementation is examined. This is based on our evaluation that the 802.21 performs better and hence we focus on MN preference based network selection.

If a cluster of 15 nodes are in a heterogeneous network environment and are connected by default to one network while the other network are down, we bring up the links as the simulation runs and generate a mih_link_detected event for the new network, followed by a series of mih_link_going_down events on the serving network. When we shut down the serving network link, and generate mih_link_down event, we observe the handovers completed to the new network with different configured parameters. In figure 20, 21 and 22, we use the mih_cost_factor as the primary selection factor. The whole network selection to network handover process denoted to start at mih_link_going_down event to mih_handover_complete event.

6.4.1 Cost Influenced Network selections

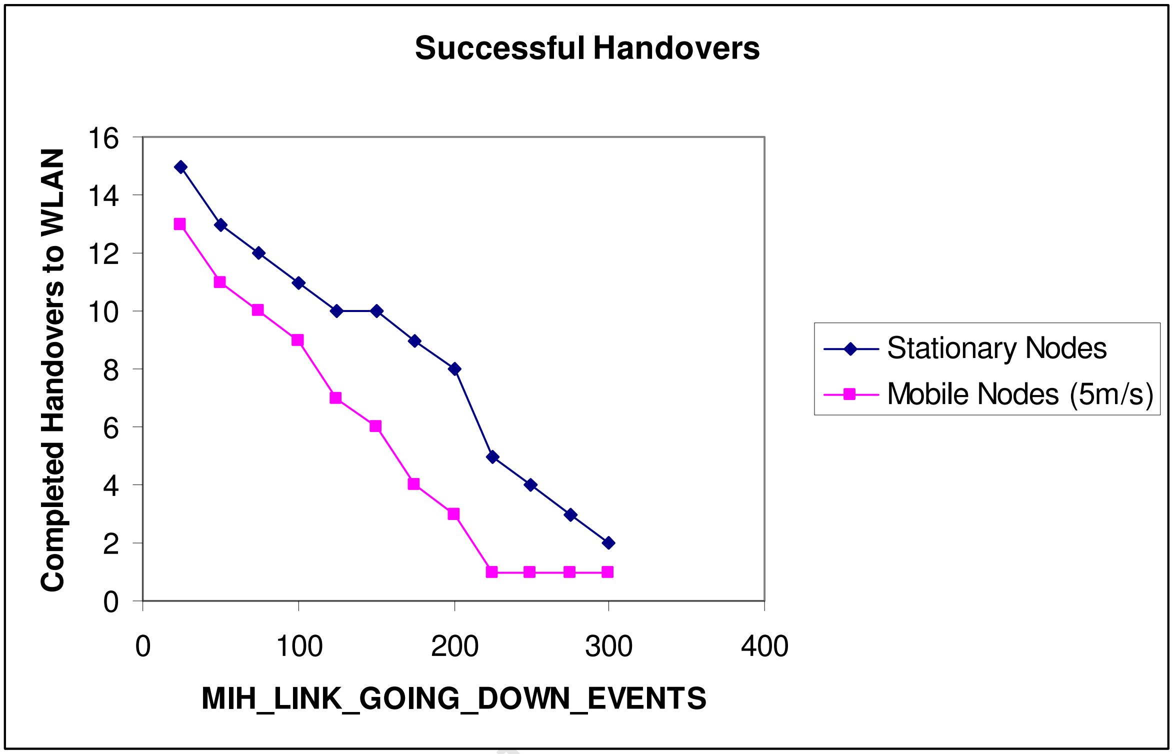

Figure 20. Cost Factor WiFi Successful Heterogeneous handovers

In this investigation, nodes are by default attached to UMTS with cost factor (2) and when WiFi is brought up and mih_link_going_down events are generated, we obtain the trace files for the completed Handovers to WiFi with cost factor (0). When we shut down the serving network link (UMTS), and generate mih_link_down event, we observe the handovers completed to the target network (WLAN) with cost factor (0). We do not capture successful handovers to WiMax cost factor (1) in this trace.

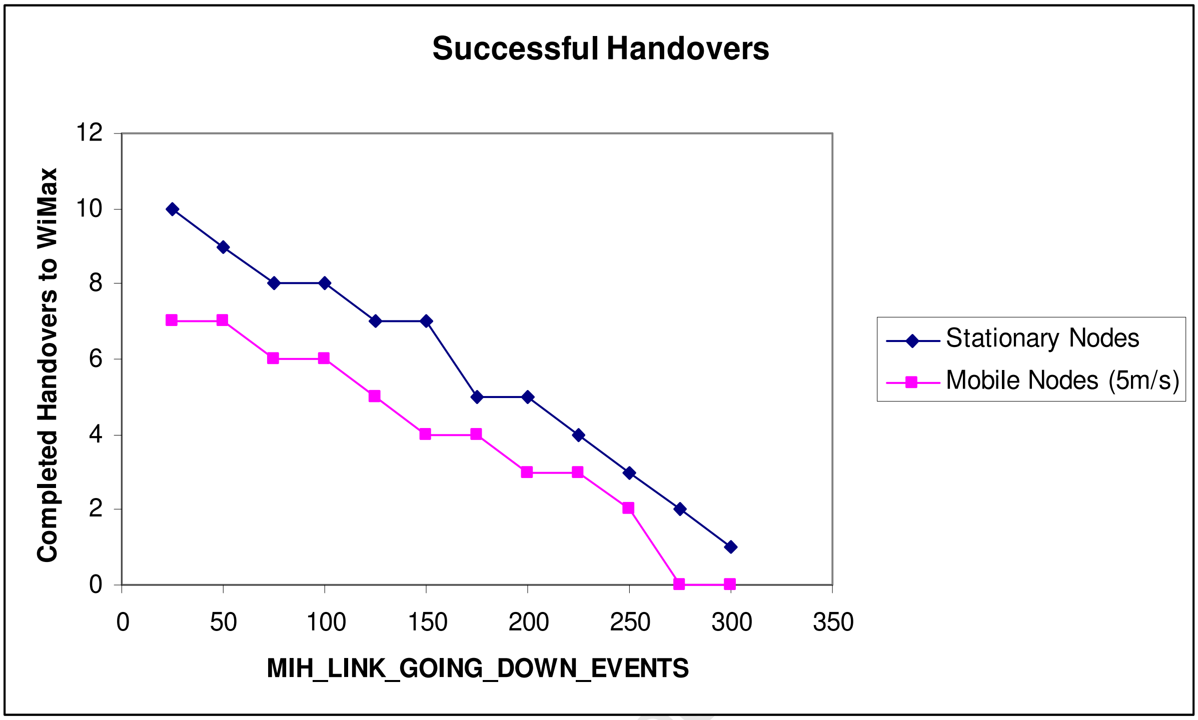

Figure 21. Cost Factor Successful Heterogeneous Handovers WiMax

In this investigation, the WiMax Base station with cost factor (1) is brought up and the current serving network WiFi cost factor (0) is shutdown. When we shut down the serving network link (WiFi), and generate mih_link_down event, we observe the handovers completed to the target network (WiMax) with higher cost factor (1). We do not capture handovers to UMTS with highest cost factor (2)

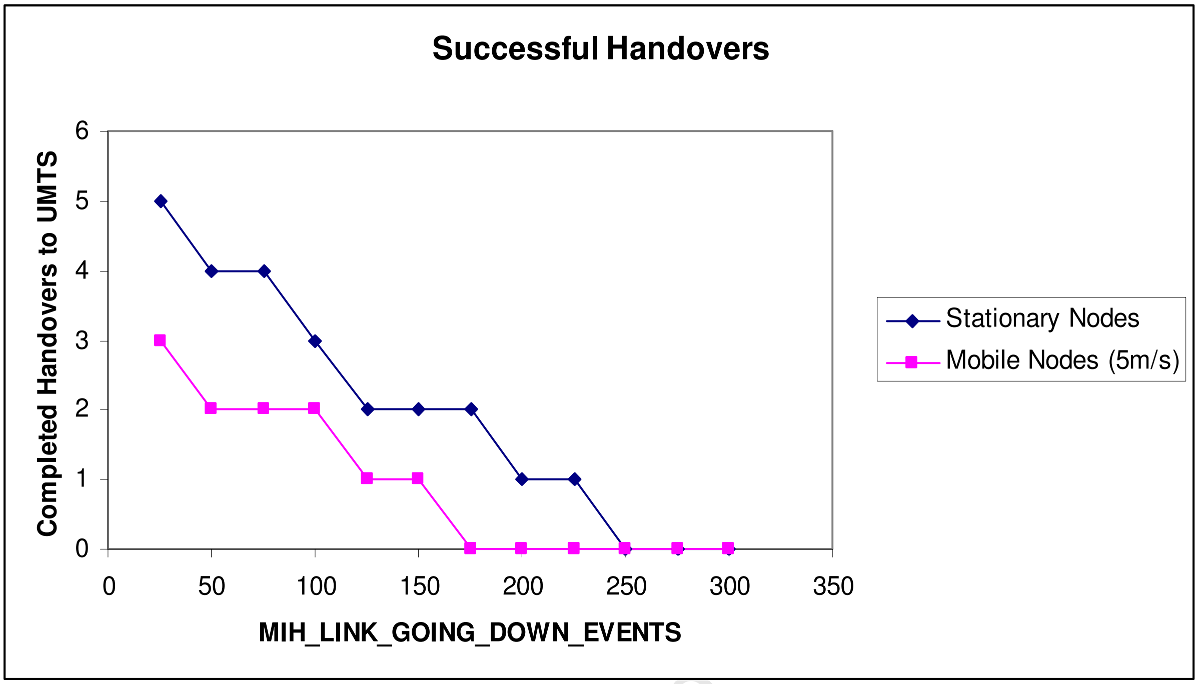

Figure 22. Cost Factor Successful Heterogeneous Handovers to UMTS

In this investigation, we attach nodes to WiMax Base cost factor (1) station by default, and we bring up the UMTS Base Station during the simulation. When we shut down the serving network link (WiMax), and generate mih_link_down event, we observe the handovers completed to UMTS with higher cost factor (2) network with different configured parameters. Handovers that are completed to the UMTS network are shown in the Figure 22. The WiFi network is shut down in this investigation.

Our analysis of the cost factor based results is that as link triggers increase, the MN is forced to initiate handovers in a bid to avoid loss of connection. In the scenario where handover is from a network with perceived worse factor than the candidate network, more handovers are successful. However, in a reverse situation, less handovers are successful due to the optimisation check that verifies that of the available networks is the best network selected, and therefore causes event roll backs which create a ping pong effect as handover is again initiated as the link triggers are received again before the link actually goes down. Overall when the link goes down less handovers are completed and stable. More packet loss is incurred in the ping-pong period.

6.4.2 Bandwidth Influenced Network selection

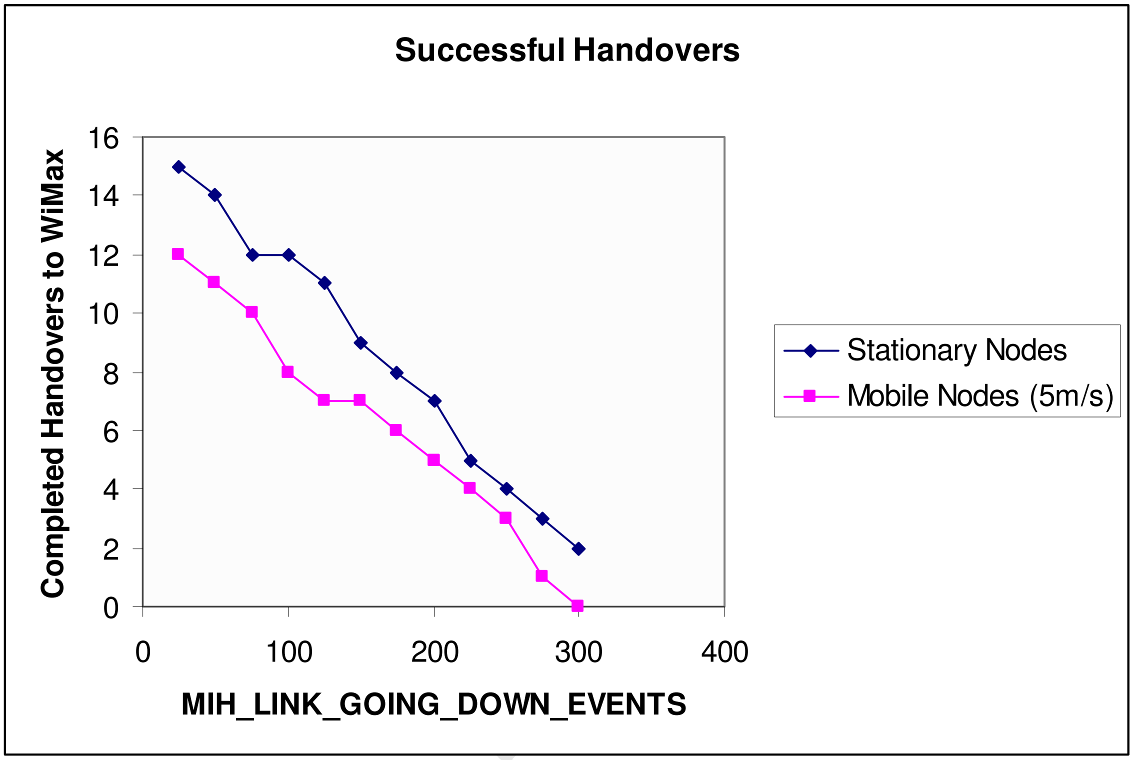

Figure 23. Successful Bandwidth factor Heterogeneous Handovers to WiMax

In this investigation and others depicted in Figures 23, 24 and 25 we use mih_bandwidth_factor as the primary selection factor for nodes in a heterogeneous network environment. We attach nodes to UMTS Base (Bandwidth factor 2) station by default, and we bring up the WiMax Base Station (Bandwidth factor 0) during the simulation. When we shut down the serving network link (UMTS), and generate mih_link_down event, we observe the handovers completed to WiMax and the results are shown in the Figure 22, while handovers to WiFi (Bandwidth factor 1) and not completed are not shown in this investigation.

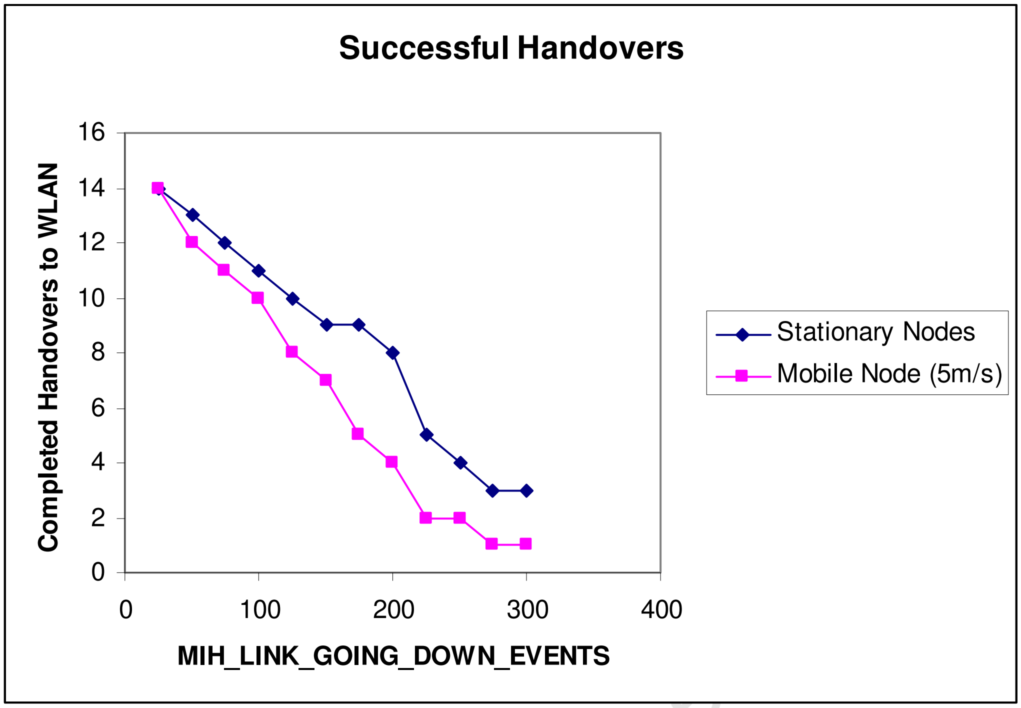

Figure 24. Successful bandwidth factor Heterogeneous handovers to WiFi

In this investigation, we attach nodes to UMTS Base (Bandwidth factor 2) station by default, and we bring up the WiFi Base Station (Bandwidth factor 1) during the simulation. When we shut down the serving network link (UMTS), and generate mih_link_down event, we observe the handovers completed to WiFi . Handovers that are completed to the WiFi network are shown in the Figure 24. The WiMax network (Bandwidth factor 0) is shut down in this investigation.

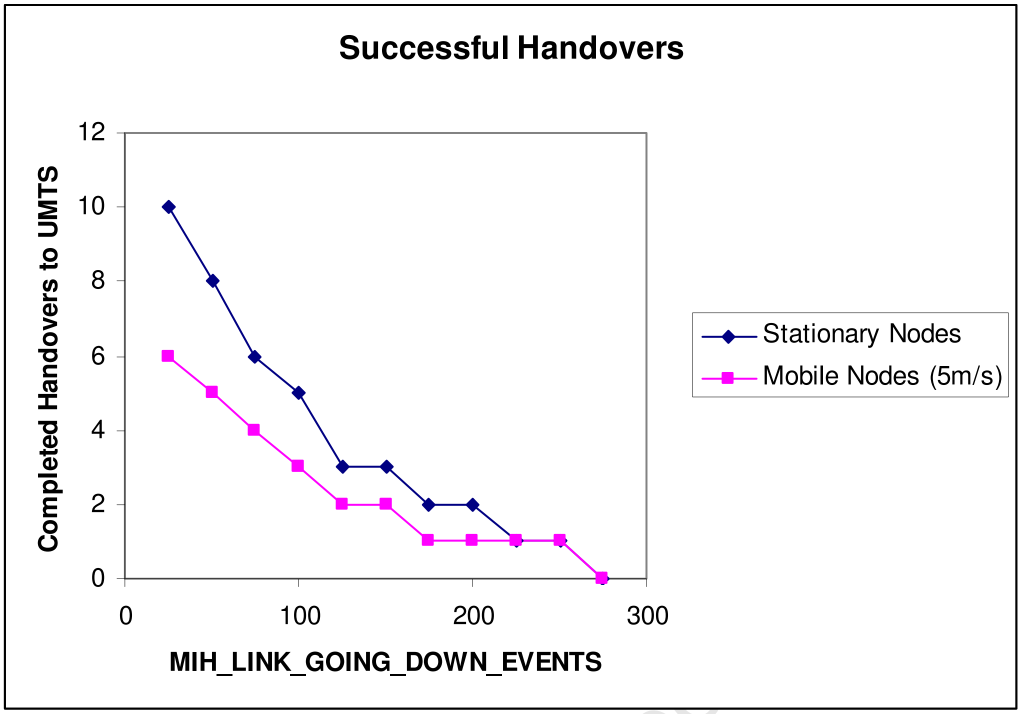

Figure 25. Successful Bandwidth factor Heterogeneous handovers to UMTS

In this investigation, we attach nodes to WiFi Base (Bandwidth factor 1) station by default, and we bring up the UMTS Base Station (Bandwidth factor 2) during the simulation. When we shut down the serving network link (WiFi), and generate mih_link_down event, we observe the handovers completed to UMTS. Handovers that are completed to the UMTS network are shown in the Figure 25. The WiMax network (Bandwidth factor 0) is shut down in this investigation.

Our analysis of the bandwidth factor based results is as link triggers increase, the MN is forced to initiate handovers in a bid to avoid loss of connection. In the scenario where handover is from a network with perceived worse factor than the candidate network, more handovers are successful. However, in a reverse situation, less handovers are successful due to the optimisation check that verifies that of the available networks is the best network selected, and therefore causes event roll backs which create a ping pong effect as handover is again initiated as the link triggers are received again before the link actually goes down. Overall, when the link goes down less handovers are completed. More packet loss is incurred in the ping-pong period.

6.4.3 Network Selection Effect on Real time/constant bit rate and Non real time Traffic

The network selection process using MIH is investigated using a stream of cbr traffic at 64Kbs to represent a voice channel in conventional digital telephony and non real time traffic such as web browsing and e-mail. We examine packet loss for a stationary node and mobile node at 5m/s and results are presented in figure

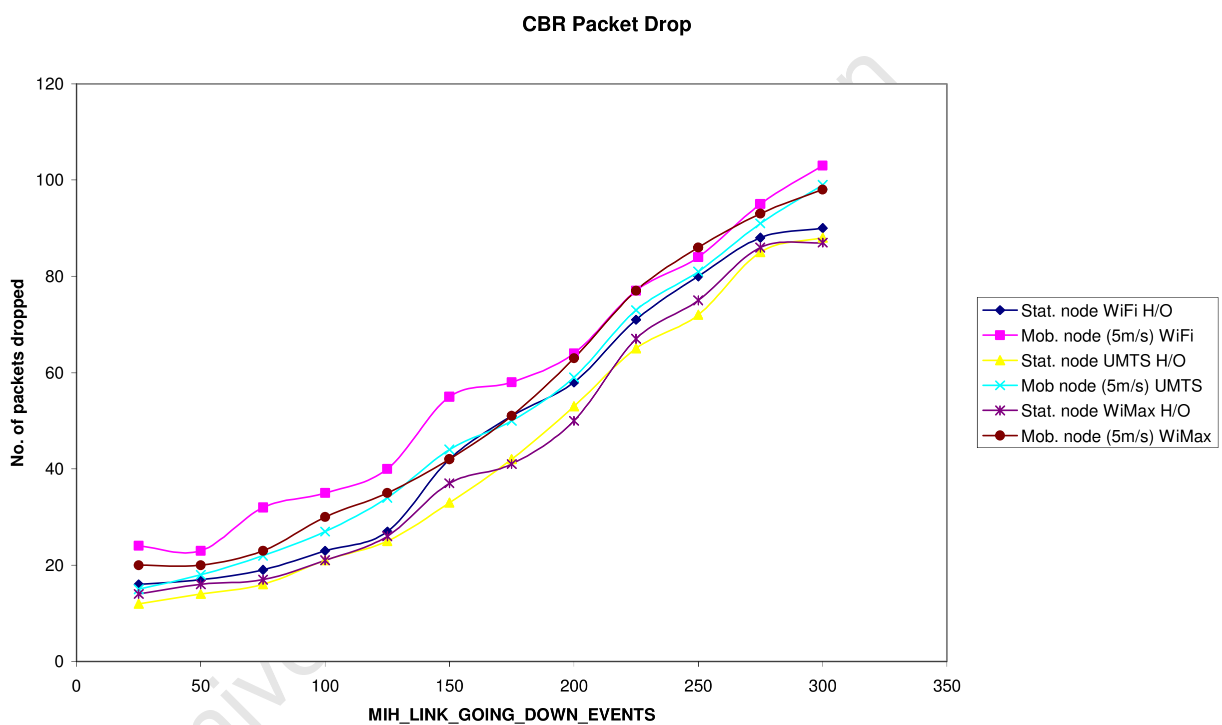

Figure 26. Constant bit Rate (CBR) Packet loss in Heterogeneous networks selection

In this investigation, we push Constant bit rate traffic as we select networks in a loop manner, from UMTS to WiFi, from WiFi to WiMax and from WiMax to UMTS. We create trace files for packet drops during the whole network selection to network handover process denoted to start at mih_link_going_down event to mih_handover_complete event.

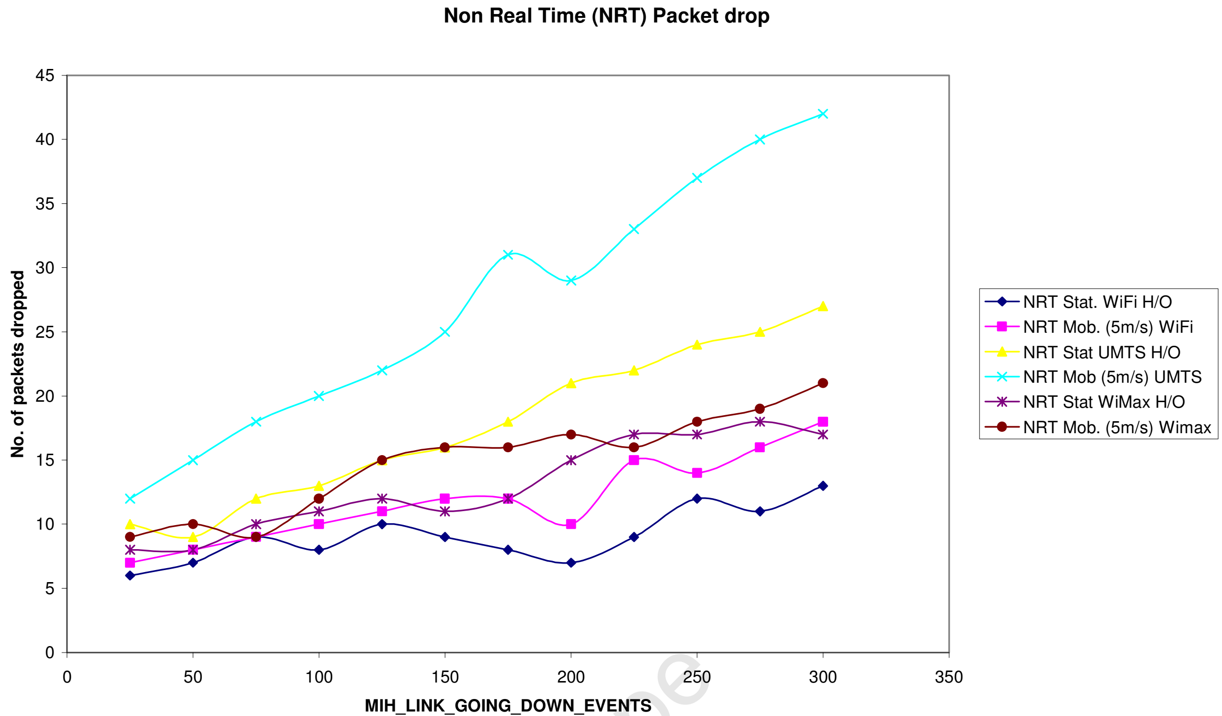

Figure 27. Non Real Time Traffic Packet drop in Heterogeneous Network selection

In this investigation, we push Non real time (NRT) traffic using NS-2 Pack-Mime Web traffic generation, as we select networks in a loop manner as in the previous investigation, from UMTS to WiFi, from WiFi to WiMax and from WiMax to UMTS. We create trace files for packet drops during the whole network selection to network handover process denoted to start at mih_link_going_down event to mih_handover_complete event.

Our analysis is that due to the events roll back that occurs as the MIH link events increase to prompt for network selection and handover, the number of packets that are dropped generally increased but the level of the increase differs for CBR traffic as opposed to non-real time. This is because CBR traffic is more sensitive to delay than non-real time traffic and thus is affected more.

For all scenarios examined, the mobile node performs badly compared to a stationary node, and we believe that this is because of the overall effect of position change and the received signal levels and thresholds measurements by the node to determine if handover is necessary.

6.5 Results Analysis and Conclusions

From the investigations and results outlined in the previous chapter, we summarily conclude that network selection in heterogeneous wireless networks environment for the appropriately equipped devices is greatly enhanced by the use of the Media Independent Handover Protocol [44]. In scenarios where the mobile node has no prior knowledge of the encountered different network architectures, the use of a Broker node can, for an optimal number of available networks also greatly enhance the mobile node's network selection by reducing the delay associated and the packet losses incurred.

Network selection in a heterogeneous environment may be based on several policies and user preferences and thus resulting in different user experiences. User preferences differ as per user requirements and may be any or a combination of such factors as the networks resources e.g. bandwidth, Quality of Service, Power usage and Cost of access [43]. In all cases, the use of MIH protocol ensures greater probability of successful handover to target network with reduced handover overhead and loss. In this thesis we, investigated Bandwidth Influenced and Cost influenced network selection, by stationary and mobile nodes in heterogeneous networks environment.

Our performance evaluations, reflected in figures 18-27, of our proposed MIH standard show a very good success trend in the network selection according to user policies. As well success in implementing user preferences through MIH standard to select and handover between different architecture networks, for the lower range of MIH link going down triggers generated i.e. between 25-100 triggers generated and the inverse of that is observed in the higher range 225-250. This is reflected in the number of completed handovers denoted by the generation of MIH handover complete triggers, as well as the measured packet loss during the handover process. In the case of non-informed mobile nodes the use of a third party node that plays middle-man to the available network and the visiting mobile node, greatly improves the network selection and handover for heterogeneous networks access.

The effect of increasing the Mih_Link_Going_Down_Events is that the frequency of transmitting these messages is increased as well, thereby reducing the threshold limit in terms of time in which the MN decides to select a network and effect a handover. In the case of better factor network being current serving/default and the MN is forced to select and handover to worse factor network being candidate network because the link is going down. If the handovers are effected, they are still adversely affected by the event roll back, caused by the MN check algorithm that ensures the selected network is the best in the factor considered. Thus if the initial network of connection is perceived to be up, roll back is effected only receive more mih_link_going_down_events and initiate handover again. Some handovers may be completed while some are cut off at event mih_link_down, when the link is shut down.

In our evaluation scenarios a failed handover is one which is completed to a different network architecture other than the MN policy target or not completed at all or affected by event roll back such that at mih_link_down event, a handover to the target network has not been completed. Thus if policy target is lowest cost factor, or highest bandwidth factor, we only capture the MIH handover complete triggers at the network assigned the factor that satisfies the policy condition. Packet loss is evaluated by obtaining the difference between the generated packets at the source and the packets received at the sink.

We also undertake to evaluate the performance of a stationary node network selection in comparison with the performance of a mobile node moving a speed of 5m/s. Generally, the performance of the stationary node is observed to be better than the mobile node in the number of completed handovers and incurring the least packet loss.

Notably also, is that in all cases of network selection and handover, there is significantly lower packet loss if non-real time traffic is being pushed as compared to when real time or Constant Bit Rate traffic being transmitted.

In conclusion, our thesis logically highlights the co-existence of heterogeneous networks, with different attractive features to mobile and stationary users as described in chapter 1. Hence the need arises or devices to select the best amongst the available network for its current and dynamic needs. However, we acknowledge the existing systems limitations, which seek to satisfy the available networks specifications, thus limiting existing systems to selection within specification at manufacture time, as described in chapter 2.

The mitigation of this problem is through the plug in of additional interfaces that satisfy the specifications of the other networks available or the development of an adaptive software defined radio. Thus a mobile node capable of the basic Mobile IP protocol can initiate handover between the different media or interfaces that it now has, as outlined in chapter 3. As the networks available for selection grow, the process of selecting one or more becomes complex and a standard approach to handle the whole process is desirable and we examine this standard approach in chapter 3.

In chapter 4, we examine the implementation approaches that can be adopted for network selection in heterogeneous networks. Using the standard approach, we design an architecture that utilises the standard's services to enhance the network selection process to reduce the associated delay and packet loss, as shown in Chapter 5. In comparison with a non-standard approach, we evaluate our design and document results in chapter 6.

The whole thesis summarily supports that the network selection process is optimised by the use of the MIH standard, and we draw this from our design's results, which generally shows less associated delay and packet loss.

We also conclude that we can further improve the performance by utilising a centralised information source such as a third party that maintains cached or readily available information of the available networks. This is because the centralised information repository caches the information and does not need to propagate new queries on MN requests. More benefits can be obtained from the centralised information repository such as brokering of connections, prices and as well as providing software repository e.g. for drivers and upgrades.

6.6 Recommendations and Future work

The Media Independent Handover Protocol is still under development and the bulk of the work on its standardisation lies with the IEEE802.21 working group. However, a lot of academic and industry work is also currently under way, with a common goal of allowing the mobile user to access service anywhere, anytime and any network.

In our view, this is very critical work for the future networking and service delivery in the Information and Communications Technologies. We envisage a future with ubiquitous access to services and networks at very low standard prices, adequate resources for user applications at any point, anytime through any available network

The realisation of this seamless mobility is still a long way from being realised, as there are other impediments beyond the network selection discussed in this thesis. These include the authentication, authorisation and accounting of foreign users in non-prior arranged roaming agreement [38] [40].

The security of these connections and call admission control for resource management in heterogeneous networks also present other challenges that need to tackled for ubiquitous network access to be a success [40].

In Network selection, several other user preferences and policies in network selection need to be identified and investigated. As well, as the aspects of Network initiated handovers for resources control versus User controlled for preferred access.

We also recommend investigation into reduction of the event rollbacks that adversely affect performance of the MIHF network selection and handovers.

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Appendix A

NS-2 Simulation

#Configuring mobile/stationary node

```
$ns_ node-config -adhocRouting $val(rp) \
                 -llType $val(ll) \
                 -macType $val(mac) \
                 -ifqType $val(ifq) \
                 -ifqLen $val(ifqlen) \
                 -antType $val(ant) \
                 -propType $val(prop) \
                 -phyType $val(netif) \
                 -channelType $val(chan) \
                 -topoInstance $topo \
                 -agentTrace ON \
                 -routerTrace ON \
                 -macTrace OFF \
                 -movementTrace OFF
```

```
for {set i 0} {$i < 15) } {incr i} {

                set node_($i) [$ns_ node]

                $node_ ($i) random-motion 0          ;# disable random motion

        }


#Setting up the nodes positions

$node_(0) set-position 0.0 0.0 0.0

$node_(1) set-position 1.0 10.111111100 0.0

$node_(2) set-position 2.0 11.122222220 0.0

$node_(3) set-position 3.0 13.133333330 0.0

                .

                .

                .

$node_(15) set-position 15.0 25.255555550 0.0
```

<u>#Creating multi-interface node</u>

```
$ns node-config  -multiIf ON

for {set i 0} {$i < $opt(nbBS)} {incr i} {

   set multiFaceNode_init($i) [$ns node  [expr 6 + $i].0.0]

}

set multiFaceNode_MN [$ns node 8.0.0]
```

$ns node-config -multiIf OFF

set sharedChannel [new $opt(chan)]

Installing MIH in multi-interface node

#set mih_node [$multiFaceNode_MN install-mih]

#$handover_MN connect-mih $mih_node

set tmp3 [$ns_node set mac_(0)]

set tmp3 [$80216_node set mac_(0)]

$handover_MN nd_mac $nd_80216_node $tmp3

$tmp3 mih $mih_node

$mih_MN add-mac $tmp3

$handover_MN nd_mac $nd_node $tmp3

$tmp3 mih $mih_MN

$mih_MN add-mac $tmp3

#**<u>Configuring UMTS base station</u>**

$ns node-config -UmtsNodeType bs \

-downlinkBW 384kbs \

-downlinkTTI 10ms \

-uplinkBW 384kbs \

-uplinkTTI 10ms \

-hs_downlinkTTI 2ms \

-hs_downlinkBW 384kbs

set bsUMTS [$ns create-Umtsnode 0.0.1] ;# node id is 1

set mih_bandwidth_factor [$ns_Umtsnode set mih_bandwidth_factor (2)]

```
set mih_cost_factor [$ns_Umtsnode set mih_bandwidth_factor (2)]

puts "bsUMTS: tcl=$bsUMTS; id=[$bsUMTS id]; addr=[$bsUMTS node-addr]"
```

#Adding 802.11 nodes

```
set opt(chan)          Channel/WirelessChannel    ;# channel type for 802.11
set opt(prop)          Propagation/TwoRayGround   ;# radio-propagation model 802.11
set opt(netif)         Phy/WirelessPhy            ;# network interface type 802.11
set opt(mac)           Mac/802_11                 ;# MAC type 802.11
set opt(ifq)           Queue/DropTail/PriQueue    ;# interface queue type 802.11
set opt(ll)            LL                         ;# link layer type 802.11
set opt(ant)           Antenna/OmniAntenna        ;# antenna model 802.11
set opt(ifqlen)        50                         ;# max packet in ifq 802.11
set opt(adhocRouting)  DSDV                       ;# routing protocol 802.11
set opt(x)             650                        ;# X dimension of the topography
set opt(y)             650                        ;# Y dimension of the topography
```

#Configuring rate for IEEE802.11

```
Mac/802_11 set basicRate_ 11Mb
Mac/802_11 set dataRate_ 11Mb
Mac/802_11 set bandwidth_ 11Mb
Mac/802_11 set bandwidth_factor (1)
Mac/802_11 set cost_ factor (0)
```

#Configuring Access Points

```
$ns node-config  -adhocRouting $opt(adhocRouting) \
```

```
-llType $opt(ll) \
-macType $opt(mac) \
-channel [new $opt(chan)] \
-ifqType $opt(ifq) \
-ifqLen $opt(ifqlen) \
-antType $opt(ant) \
-propType $opt(prop)    \
-phyType $opt(netif) \
-topoInstance $topo \
-wiredRouting ON \
-agentTrace ON \
-routerTrace OFF \
-macTrace ON  \
-movementTrace OFF
```

#Configuring IEEE802.16

```
set seed                    5555
Mac/802_16 set scan_iteration_      2
set use_going_down                  1
if {$use_going_down == 1} {
   Mac/802_16 set lgd_factor_       1.1
} else {
   Mac/802_16 set lgd_factor_       1.0
}
Mac/802_16 set scan_duration_       50
```

```
Mac/802_16 set interleaving_interval_ 40
Mac/802_16 set dcd_interval_        5 ;#max 10s
Mac/802_16 set ucd_interval_        5 ;#max 10s
set default_modulation             OFDM_16QAM_3_4 ;#OFDM_BPSK_1_2
set contention_size                5 ;#for initial ranging and bw
Mac/802_16 set t21_timeout_         0.02 ;#max 10s, to replace the timer for looking at preamble
Mac/802_16 set client_timeout_      50
#define coverage area for base station:
#default frequency 3.5e+9 hz
Phy/WirelessPhy set Pt_ 15
Phy/WirelessPhy set RXThresh_ 1.215e-09        ;#500m coverage
Phy/WirelessPhy set CSThresh_ [expr 0.8 *[Phy/WirelessPhy set RXThresh_]]
# Parameters for wireless nodes
set opt(chan)          Channel/WirelessChannel    ;# channel type
set opt(prop)          Propagation/TwoRayGround   ;# radio-propagation model
set opt(netif)         Phy/WirelessPhy/OFDM       ;# network interface type
set opt(mac)           Mac/802_16                 ;# MAC type
set opt(ifq)           Queue/DropTail/PriQueue    ;# interface queue type
set opt(ll)            LL                         ;# link layer type
set opt(ant)           Antenna/OmniAntenna        ;# antenna model
set opt(ifqlen)        50                         ;# max packet in ifq
set opt(adhocRouting)  NOAH                       ;# routing protocol
set opt(nbMN)          n                          ;# number of Mobile Nodes
set opt(nbBS)          1                          ;# number of base stations
```

```
set opt(x)              3000                    ;# X dimension of the topography
set opt(y)              3000                    ;# Y dimension of the topography
set opt(mnSender)       1
#IEEE802.16 Node
set nd_80216_node [$80216_node install-nd]
set handover_MN [new Agent/MIHUser/IFMNGMT/MIPV6/Handover/Handover1]
$nd_80216_node set-ifmanager $handover_MN
$multiFaceNode_MN install-ifmanager $handover_MN
set mih_bandwidth_factor [$ns_80216_node set mih_bandwidth_factor (0)]
set mih_cost_factor [$ns_80216_node set mih_cost_factor (1)]
```

Appendix B

Simulation Environment & Software

Advent 7105 (Designed for Windows XP -Windows Vista Capable)

Windows XP Media Center Edition

Window XP Service Pack 3

1024MB DDR-Ram

ATI Radeon® Xpress 200M with PCI Express® Graphics (up to 128MB shared memory)

60 GB HDD

1GB HDD memory swap

Mobile AMD® Sempron™ 3000+ Processor, 795MHz

15’4” Widescreen TFT (XGA 1280x800)

Red Hat Cygwin version 3.00.16(14) –release (i686 pc-Cygwin)

XWin version 6.8.2.0-4 X11R6 and Xterm

Tcl release 8.4.11

Tk release 8.4.11

Otcl release 1.11

TclCL release 1.17

TclDebug tcl-debug release 1.9

Nam release 1.11

Xgraph version 12

Topology Modeller

ZLib version 1.2.3

NS-2.29 (NIST Seamless & Mobility Package)

Appendix C

Accompanying CD Rom

This Thesis is supplied with accompanying CD Rom containing:

1) Thesis document

2) NS-2.29 NIST Seamless and Mobility Package

3) Simulation Files

4) Reference papers used in the Thesis